Design Patterns for Work and Organization Structures to Improve Performance in Public-Private Partnerships

by

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SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF

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ABSTRACT

A project planning phase is critical to the success of the Public-Private Partnership (PPP) project. The design of a work breakdown structure (WBS) is an essential and effective task in the planning phase. The purpose of this paper is to introduce a new way of designing a WBS through the Work Breakdown Design Pattern Generator (WBDPG). Compared to conventional ways of creating a WBS, the WBDPG helps to design a WBS based on the ability to compare the alternatives and their potential benefits. The core hypothesis of this research is that a well-designed – and thus better performing – WBS should increase alignment between situational project requirements and the project's product breakdown structure (PBS) or organizational breakdown structure (OBS). In order to consider this alignment and tradeoffs, a method is proposed which uses morphological and domain mapping matrices to conduct a tradespace and scenario analyses. With this "generator" method, combinations of different breakdown rules across several layers of hierarchy lead to predicted varying levels of performance of the project. For example, a WBS made of functional breakdown rules shows high alignment with the PBS, thus such projects result in better performance related to the product structure. In contrast, a WBS driven by resource breakdown rules aligns highly with the OBS, resulting in high performance related to the organizational structure. In a case where locational difference has a big impact on the project, a WBS made of geographical breakdown rules is likely to lead to better performance. The research concludes that the Work Breakdown Design Pattern Generator can forecast different performance given WBSs designed through different combinations of breakdown rules, and resulting variation in alignment across breakdown structures. Given that PPP projects are often complex, with large-scale and many stakeholders, the method demonstrates a way that structural alternatives can be generated so that the various partners in dialogue can shape their work approach efficiency in the early phase. The research has several limitations and opportunities for extension. In this paper, the organization structure and the product structure are assumed as given. Also, any refinement or change loops to the WBS during the project were not considered.

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PPP	Public-Private Partnership
WBS	Work Breakdown Structure
BR	Breakdown Rule
SPS	System Problem Statement
UNECE	United Nations Economic Commission for Europe
PBS	Product Breakdown Structure
OBS	Organizational Breakdown Structure
DSM	Design Structure Matrix
DMM	Domain Mapping Matrix
MDM	Multi Domain Matrix
ConOps	Concept of Operations
OPM	Object Process Methodology
PMI	Project Management Institute
PMO	Project/Program Management Office
PMBOK	Project Management Body of Knowledge

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1. Introduction

1.1. Motivation

Many researchers have found that governments began to focus on Public-Private Partnership policy and tried to take advantage from it after the 2007 global financial crisis (Akintoye et al., 2005). Public-Private Partnership (PPP) is a type of procurement model widely used by governments and international organizations to carry out complex and large-scale projects. Most of conventional public sector projects were performed solely by a government or contractor. The developments, management, finance of the project were handled by one organization. On the contrary, due to the unique risk sharing and multiple party involvements, PPP delivers better schedule and cost performance of the project. Through PPP, it was possible to manage public resources more efficiently, and to bring public services on time with better quality. This is because the private sector is ahead of the technology and rich experience that are required for large, complex projects. According Seok (2017), the World Bank reported the increase in infrastructure PPP projects during 2004 and 2014 has been from US $23.2 to $107.5 billion. In Europe, PPP investments have increased almost six times during the 15 years since 1990. Engel et al. (2011) note that the use of PPPs to provide U.S. infrastructure has increased nearly five times between 1998 and 2008.

However, due to the high risk in resource-sharing, multiple party involvements, large-scale, and the complexity of the project, PPP projects can easily fail. One example of failure is the Mexico's toll road program. In Mexico, between 1987 and 1995, 52 projects (25 competitively tendered) were awarded. But by the end of 1995, 34 projects run out of money and eventually the project ended up leading to very high tolls. This was due to the miscalculation of the capacity and lack of feasibility study regarding the new roads. Failure of proper design of the project led to an average 25% overrun of construction cost, and average 30% less revenue than was expected. The government took over 23 projects and paid outstanding debt to Mexican banks and construction companies (Hodges, 2006). Similarly, Portugal used PPP for the first time to build new infrastructure more efficiently in the mid-90s. However the lack of experience with PPP insufficient knowledge led to poor project management. According to the World Back report (2008), Portugal's early PPPs were subject to constant delays and cost overruns. By 2003, the country's PPP-related liabilities amounted to 10% of GDP. Weak public sector capacity was evident in insufficient risk transfer to the private sector and delays in giving government approvals on essential land and environmental issues. The Don Muang toll way project, Bankok elevated transport System, and Second expressway system are another examples of PPP failures found in Thailand. These failures were due to the inaccurate forecast of the market, changes in the government, and dissonance between the parties involved (Tam, 1999).

Among the several failure factors in PPP, some studies mention the importance of the early planning phase. Bachy and Hameri (1997) looked into the relationship between the planning phase and risk analysis. According to them, experiences show that emphasizing quality during the planning phase can reduce the actual production time and risk liability. Risk management has higher effect when they are started in the early phase than later on. And improving the viability in international PPP projects also comes from the early-stage planning (Seok 2017). They show how the early planning phase can highly impact the performance and success of the project.

But studies regarding the early stage of projects are not sufficient. Most research focuses on identifying critical success factors (CSFs) in the context of the whole project and deriving quantitative importance to assess the risk. One of the key parts in the planning phase is creating a Work Breakdown Structure (WBS). A WBS is "a deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables" (The PMBOK Guide—Third Edition). Many papers emphasize the importance of WBS as it is the actual start of the project definition. If the project scope is clearly defined before actual implementation, there is a high chance that the project would end successfully. Homer and Gunn (1995) note "the intelligent structure of work breakdowns is a precursor to effective project management". Kerzner (1997) also mentioned "a WBS provides the framework on which costs, time, and schedule/performance can be compared against the budget for each level of a WBS".

As a result, a good WBS will most likely lead to the high performance and success of the project. There are many ways to create a WBS but surprisingly little agreement on the best method for creating it. This is because different breakdown rules are used to create a WBS depending on the intuition of the project manager, nature of the organization, and other factors. In addition, the same WBS with different organizations might lead to different outcomes, and different WBSs might lead to similar results. By understanding various breakdown rules and their relationship with the nature of the project and organization, there seems to be a possibility to select the appropriate WBS for a project. A WBS that consists of an appropriate set of breakdown rules can maximize the performance of the project.

1.2. Problem Statement and Research Questions

Successful PPP project can give benefit to both public and private sector. If one can find a way to mitigate the possible risk in the early phase of the project, he/she could save a lot of effort and resource. A WBS is one of the critical tasks in the early project phase, and many large-complex projects are highly affected by the creation of a WBS. In addition PPP projects seem to be influenced by the complex organizational structure. If one can understand how a WBS is formed, especially according to the different decision rules and situation, and if one could see how those elements affect the performance of the PPP project, the PPP project can be performed much more efficiently and successfully.

In this paper above problem is approached with system thinking. System thinking is to think a phenomena or a problem as a system and to understand or solve it with a holistic approach. Thinking it as a system can be done by understanding the boundary of the system and identifying its form, function and the relationships between entities within the boundary. Compare to the linear thinking where every phenomena is explained by cause and effect, system thinking uses circular causal thinking where things are explained by continuous loop of relationships and affects (Lewis, 2007) (Tonder and Bekker, 2002). The 'Design of a WBS in PPP' will be set as a system. The approach to the problem will be started by establishing thc system problem statement (SPS). Through a To-By-Using scheme defined by Edward Crawley, Bruce Cameron, and Selva (2016), SPS is stated as figure 1.

To Design the most effective work breakdown structure

By Architecting Work Breakdown Design Pattern Generator

Using Tradespace analysis and Domain Mapping Matrix techniques

Figure 1. System Problem Statement

In order to understand and solve the problem, we have identified two research questions that were to be answered by this thesis.

RQ1. What are the types and characteristic of breakdown rules of a WBS?

RQ2. How do different WBSs give impact to the performance of a PPP project?

This thesis is structured as follows. Chapter 2 summarizes a literature review that is related to the problem. Literatures regarding Public-Private Partnership, Work Breakdown Structure, Product Breakdown Structure, Organizational Breakdown Structure, Design Structure Matrix and Domain Mapping Matrix are reviewed. Chapter 3 lays out the research approach and hypothesis. Chapter 4 presents the system thinking principles that will be used as guidance for architecting and analyzing the problem. Chapter 5 presents the high-level concept of operations for the system. Chapter 6 illustrates the key processes of the design and explores the architecture of Work Breakdown Design Pattern Generator with its results. Chapter 7 lays out the verification and baseline scenario. Chapter 8 presents scenario analysis with two other scenarios. Finally Chapter 9 recaps the findings of this thesis and suggests future work.

2. Literature Review

2.1. Public-Private Partnership (PPP)

This section reviews the various definitions of PPP throughout the literature and its unique feature that distinguishes PPP from the conventional procurement model. Also it will cover the benefits of adopting PPP and the success factors of PPP project.

2.1.1. Definition

Public-Private Partnership (PPP) is a contractual arrangement between public sector and private sector for commonly long term, large-scale complicated infrastructure projects. The definition of PPP slightly differs from organization to organization. United Nations Economic Commission for Europe (UNECE) define PPPs as "innovative, long term, contractual arrangements for developing infrastructure and providing public services by introducing private sector funds, expertise and motivation into areas that are normally the responsibility of government". The European Commission define PPP as "a partnership arranged between two or more parties who have agreed to work cooperatively toward shared and/or compatible objectives and in which there is shared authority and responsibility; joint investment of resources; shared liability or risk taking and ideally mutual benefits". The PPP Knowledge Lab from The World Bank defines a PPP as "a long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance". Canadian Council for Public Private Partnerships (2001) define it as "a cooperative venture between the public and private sectors, built on the expertise of each partner that best meets clearly defined public needs through the appropriate allocation of risk resources and rewards". HM Treasury of UK sees PPP as "an arrangement between two or more entities that enables them to work cooperatively towards shared or compatible objective and in which there is some degree of shared authority and responsibility, joint investment of resources, shared risk taking and mutual benefit".

The biggest distinction of PPP to conventional contract is the allocation and sharing the risk.

Unlike other procurement methods, PPP does not take responsibility by one single organization. Usually financial resource and technology comes from the private sector, and the security for a long term operation and stable recollection are responsible for the public sector. It is hard to succeed a PPP project without proper allocation of the risk. So more careful identification of the risk and allocation to a suitable party are necessary in PPP projects (Li et al., 2005a). Also the PPP project involves multiple stakeholders and participants. This leads to a careful consideration of the needs and satisfaction of each stakeholder for every stage of the project process, such as planning, developing, financing, maintaining, etc. A long-term, large-size complex project is another unique characteristic of PPP project. PPP is noted for its long-term partnership usually from 5 years at minimum up to more than 30 years between the public sector and the private sector. Therefore, for its effective operation, strong and sustainable relationships are required between the parties (Middleton, 2000). International PPP project differs from other PPP projects in a sense that different legal standard, working environment, communication issues are added. Thomal et al. (2006) also mention that PPP project has various barriers to financial commitments due to external uncertainties.

2.1.2. Benefits

Designing a public infrastructure or public service usually costs a lot. Technical knowledge and rich experiences are required for the implementation, operation, and maintenance. However it is difficult for public sector to allocate such large amount of capital in a risky project, and to keep up with latest technology. These complex, large-scale projects are likely to fail if they are driven by public sector alone, or they are likely to perform poorly. By using PPP, private sector can take over the capital and technology risks with appropriate collection policy. The rich experience and expertise of the private sector can enhance the performance and possibility of success of the project (UNECE, 2012). Robert (2011) notes "the main advantage of a PPP is that the government can improve public services without using large capital sums of public money". Syracuse University studied the benefits of PPP to the public sectors. They found that compared to public sector, private sector tend to better utilize the control system. So, by sharing the risks and allocating to a party who can mitigate better, public sector can achieve quality improvement, cost certainty, schedule certainty, and technical innovation (Brown et al., 2016).

2.1.3. Critical Success Factors (CSFs) of PPP

As the positive effects of the PPP were explored, many studies to organize the critical success factors of PPP were made. There were inconsistent factors due to different industries, but a common CSF for PPP business was found. Chou (2015) summarized the CSFs of PPP in four countries (China, Taiwan, United Kingdom, Singapore) from several literatures; Chan et al. (2010), Chou et al. (2012), Hwang et al. (2013), and Bing et al. (2005b). He divided the factors into five groups, which were stable macroeconomic environment, shared responsibility between public and private sectors, transparent and efficient procurement process, stable political and social environment, and judicious government control. Stable macroeconomic environment was important because it affected the financial problems and collecting fees during and after the operation. This included macroeconomic environment, sound economic policy, favorable legal framework, stable macroeconomic condition, appropriate risk allocation and risk sharing, available financial market, etc. The second group, shared responsibility between public and private sectors, has CSFs like responsibility between public and private sectors, shared authority between public and private sectors, commitment and responsibility of public and private sectors, project technical feasibility, and thorough and realistic assessment of the cost and benefits. These factors were critical since PPP involves multiple parties and is based on risk sharing. If the responsibilities among the parties are not clear, or if there is no strong commitment among the parties, the large-scale complex project can so easily turn into failure. Along with the second group the third group, transparent and efficient procurement process, is also related to the project management. In PPP project, a chunk of works are developed and operated by several private sectors. Unclear definition of roles and loose procurement management can easily advance to inefficiency and corruption. CSFs in this group are competitive procurement process, transparency procurement process, well-organized and committed public agency, clarification of contract documents, clear defined responsibilities and roles, etc. Stable political and social environment group includes factors like political support, social support, outstanding private consortium, and government support. These factors mostly evolve from outside of the project and are hard to control. Lastly judicious government control refers to the government involvement in case unexpected or external changes for guarantying certain security.

Zhang (2005) used a systematic research approach and identified various success sub-factors and classified them into five main CSFs. The five main CSFs are favorable investment environment, economic viability, reliability of concessionaire consortium with strong technical strength, sound financial package, and appropriate risk allocation via reliable contractual arrangements. Favorable investment environment CSF is a feasibility of the project in the context of political, legal, and general environment. Stable political system, favorable economic system, adequate local financial market, predictable currency exchange risk, predictable and reasonable legal framework, government support, supportive and understanding community, public interest of the project, etc. are included in this CSF. Economic viability factor is similar to Chou's (2015) stable macroeconomic environment. It considers economic feasibility such as long-term demand for the products/services offered by the project, limited competition from other projects, sufficient profitability of the project to attract investors, long-term cash flow that is attractive to lender, and long-term availability of suppliers. The third CSF, reliable concessionaire consortium with strong technical strength, refers to the reliability of the private sector. Whether they have strong leadership, effective project organization structure, strong and capable team, good relationship with the government, rich experience in PPP, sound technical solution, innovative solution, etc. are the sub-factors of this CSF. Finally, due to the critical effect of risk allocation, appropriate and reliable risk allocation in concession agreement, shareholder agreement, design and construct contract, operation agreement, supply agreement, guarantee letters are picked as a CSF.

Raisbeck and Tang (2013) looked into the critical factors that gave impact at the early design phase. They tried to understand what capabilities are important in the development of a design process. They categorized the design development sub-criteria into four groups; design, design management, design support, and design infrastructure distinctions. The first two were exploratory distinctions and the latter two were exploitative distinctions. Raisbeck and Tang found out that exploratory activities were thought to be more important than exploitative activities. Their research indicates that the effective management of an initial design is a critical factor in PPP projects.

Osei-Kyei and Chan (2015) methodically reviewed studies on the CSFs for implementing PPP from some selected top tier academic journals from 1990 to 2013. He depicted 37 CSFs from 27 different publications. The top ten duplicated CSFs were risk allocation and sharing, strong private consortium, political support, community/public support, transparent procurement, favorable legal framework, stable macroeconomic condition, competitive procurement, strong commitment by both parties, clarity of roles and responsibilities among parties. CSFs that were closely related to the project planning were appropriate risk allocation and sharing, clarity of roles and responsibilities among parties, open and constant communication, detailed project planning, clear project brief and design development, etc.

Holgeid and Thompson (2013) focused on the reasons why large public projects fail. They specifically looked into the large IT projects and highlighted the lack of leading skills as well as change management skills. Additionally, they found that "contextual factors such as size and volatility" were the CSFs in public IT projects. Samii et al. (2002) emphasized the six requirements for good fit, effective PPPs. They are resource dependency, commitment symmetry, common goal symmetry, intensive communication, alignment of cooperation learning capability, and converging working cultures. And in order to make it work, he introduces six conditions: leadership, partnership team, intensive communication, consensus-building approach, immediate implementation, and alignment of cooperation learning capability. Jamali (2004) mentioned about several useful principles and guidelines for project preparation. Among the guidelines from other papers and experiences, he suggested a clear definition of targets and goals; a timely and transparent mapping of all costs, revenues and profitability aspects of a PPP; clear boundaries, measurable output performance and transparency; specific reporting and record keeping requirements; a strong central structure at the level of central administration; an appropriately designed legal framework; a consideration of environmental, safety, and health responsibilities; and control over and close monitoring of monopolistic.

2.2 Importance of Project Planning

Project planning is an activity of organizing required work and establishing a formal plan to accomplish the project's goals (Meredith and Mantel 1995). It is known as one of the critical success factors in a project. Since the project planning is the first process of project management, how it is performed may significantly change the future direction (Zwikael and Globerson, 2004). King et al. (1988) also emphasizes the importance of the initiation phase relative to other phases in the project life cycle. Dvir et al. (1999) notes "in a recent study of development projects in Israel indicate that the origination and initiation phase, in which major decisions are made, such as deciding the project's objectives and planning the project's execution, has the most influence on the project's success". PMBOK classifies developing project management plan, creating a WBS, defining activities, estimating costs in the planning process group (PMBOK GUIDE – Fourth edition, 2008).

And among many actions in planning phase, Globerson (1994) noted that the work breakdown structure is the "backbone of the proper planning, execution and control of a project". Tonder and Bekker (2002) also mention that a WBS "forms the bases for the planning, estimation, scheduling, monitoring, management and control of all project activities". They argue a clear and comprehensive WBS is important for project success. A WBS that fits the organizational structure and the project system profile will facilitate an efficient allocation of resources for a particular company.

2.3. Work Breakdown Structure (WBS)

In this section, the concept of a work breakdown structure and its form will be covered. Also this section will review how to create a WBS and what are their functions. It concludes with looking into the meaning of a good WBS.

2.3.1. Definition

Work Breakdown Structure (WBS) is a structure that illustrates the project how they are broken into small chunks of manageable works. According to Abbasi et al. (2000), WBS is an "organizational chart that breaks the project into subsystems, components and tasks that can be readily accomplished. It is used for scheduling, pricing and resource planning". The PERT Coordinating Group 8 defines a WBS as a "family-tree subdivision of a program that begins with the end objectives, and subdivides these objectives into successive smaller subdivisions" (PERT, 1962). PMBOK Guide refers a WBS as a "deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables, with each descending level of a WBS representing an increasingly detailed definition of the project work" (PMBOK Guide – Fourth Edition). Norman et al (2010) looked into the change of definition of a WBS by version from PMBOK: 1987, 1996, 2000, 2004, and noted a core characteristics of a WBS as figure 2.

- Is deliverable-oriented
- Is hierarchical and constructed in such a manner that (a) each level of decomposition includes 100% of the work of its parent element, and (b) each parent element has at least two child elements
- Defines the full scope of the project and includes all project related work elements including all internal, external and interim deliverables
- Includes only those elements to be delivered by the project (and nothing that is considered out of scope)
- Uses nouns and adjectives to describe the deliverables, not verbs
- Employs a coding scheme that clearly depicts the hierarchical nature of the project
- Contains at least two levels of decomposition
- Is created by those performing the work with technical input from knowledgeable subject matter experts and other project stakeholders
- Includes Projector Program Management at level 2 of the hierarchy
- Includes a WBS Dictionary that describes and defines the boundaries of the WBS elements
- Contains work packages that clearly support the identification of the tasks, activities and milestones that must be performed in order to deliver the work package
- Communicates the project scope to all stakeholders
- Is updated in accordance with project change management procedures

Figure 2. Core Characteristics of a WBS from Norman et al. (2010)

A WBS is decomposed into work packages (PMBOK Guide – Third Edition). Work packages are the smallest manageable work units that are needed to accomplish specific task. They tell us where the responsibility of the work lies and which work can be further planned independently (Bachy and Hameri, 1997). As a work package is the smallest unit that guides a set of works, it should contain the scope of work, starting and ending point of the work, estimated budget for the work, responsible organization unit for the work (Taylor, 2003).

2.3.2. Breakdown Rules

A breakdown rule is the decision criteria for the decomposition and it varies from project to project. The top 2~3 levels in the WBS reflect group of works that produce major deliverables. These levels can also outline the major phases of the project's life cycle. The lowest level of a WBS contains all the planned work (Helgason, 2010). PMI note that the deliverable-oriented WBS provides following benefits to the project: better communication to project sponsors, stakeholders, and team members; more accurate estimation of tasks, risks, timelines, and costs;

increased confidence that 100% of the work is identified and included; and a foundation for the control processes within the project (PMI, 2006). Norman and Brotherton (2008) depicted the most common forms of a WBS decomposition are breakdowns by table 1.

Table 1. Common Forms of a WBS. Refined from Norman and Brotherton (2008)

Breakdown Rule	Description
Functional	• Decomposing the project by business function • Facilitates communication of responsibility to the stakeholders
Role-based	• facilitates communications of responsibility for deliverables
Method-oriented	• Organizing the project's deliverables based on a defined methodology or delivery process • Facilitates the understanding of the project's outcomes for the project team and other project stakeholders
Deliverables (components)	• Most commonly used breakdown rule • It is independent of the project organization or execution methodology

Golany and Shtub (2001) also show various WBS formats using different breakdown rules. He classified into five kinds of the breakdown rules; technology, project life cycle, geographical, logistic, and subsystems, and depicted each characteristic as table 2.

Table 2. Types of a WBS refined from Golany et al (2001)

Breakdown Rule	Description
Technology	• Good match with organizations that are structured in a functional hierarchy • Favorable by managers preferring strong central control of the project
Project Life Cycle	• Decompose by the stages of the project life cycle • Good match with certain organizations that elect to orchestrate their activities by timing

Geographical	• Preferred when the circumstances (culture, language, government, law, etc.) are dramatically different by location • Good match in decentralized management practices in which local managers are empowered with full authority and responsibility
Logistic Oriented	Usually in supply chain management projects
Subsystems	Entirely dividing into major subsystems

In Practical Standard for a WBS (PMI, 2006), the decomposition criteria are thought to be vary depending on the needs and requirements of the project. Some of the examples were illustrated as follow.

- Work based or sub-deliverable based decomposition is more suitable where organization is structured along very strict functional lines.

- Sub-assembly based decomposition is more suitable where organization is more to the "projectized" organization without functional divisions.

- Time phase based decomposition is more suitable where new product development proceeds in sequential stage-like phases.

- Geographical based decomposition is more suitable where organizations have regional offices.

Bach and Hameri (1997) denote the top level of a WBS as the project or the final product. And the second level as main component or functions or geographical locations. The third level as whichever that is different from the second level. However, since the existing organizational structure dictates the upper level breakdown of the WBS in practice, they mention the WBS should coordinate with the existing OBS in some level.

Taylor (2003) also introduces other types of WBSs which use different breakdown rules along with deliverable-oriented WBS. Verb-oriented WBS is a task-oriented WBS that decomposes the works for final deliverable in terms of the required process or action. Noun-oriented WBS refers to a deliverable-oriented WBS, sometimes known as product breakdown structure, which decomposes the project work by physical or functional sub-components that consists the project deliverable. Time-phased WBS decomposes the project deliverable by major time phases. It is usually used in long term project. Other WBS types he mentioned were organization-types, geographical-types, cost breakdown types, and profit-center types. He also notes that among the all levels on a WBS, second level, which is the first decomposition, is often the most important. This is because the first decomposition can vary the structure of WBS in different ways and the estimation of cost, schedule, and responsibility can change if they are grouped in different manner.

In many cases, the choice of which breakdown rule to use depends on the project manager and the organization. Sometimes they follow by the organization's standard, and sometimes project manager intuitively choose what seems to be most suitable. There are no concrete rules of when and which the breakdown rules are used. Norman and Brotherton argue that a breakdown rule is a User-Related characteristic for the project or program. However, although different breakdown rules are used, WBSs for the same project mostly have the same work packages. The main difference is "the organization of the higher level WBS elements" (Norman and Brotherton, 2008). Bachy and Hameri (1997) note that the way project manager defines each level directly affects the organizational structure of the project. The upper levels in the decomposition help project manager to easily assess the performance, communicate about accomplishment, and measure cost and schedule performance. In order to avoid confusion, it is best to define the levels of a WBS prior to construction (PMI, 2006)(Helgason, 2010).

2.3.3. Level of Decomposition

Then to what level should one decompose the project? The level of detail corresponds to the complexity of the deliverable and to the expertise of the organization. An appropriate level that could well balance between complexity, communications, risk and the need for control should be chosen (Norman and Brotherton, 2008). Taylor (2003) mentions an appropriate level of breakdown is the level where it is no longer possible to define planned outcomes, and when only details are remaining.

According to Kiewel (1998), some organizations have general guidelines for deciding the size of work packages by the unit of effort or time. However Raz and Globerson (1998) contend that such kind of decision usually does not consider the specific content of the work packages. They argue key characteristics of the work contents such as cost and schedule estimation, responsibility assignment, progress control, network construction, internal cohesion, cash flow, etc. should be considered in the decision of the proper level of decomposition.

Too much deep-level decomposition sometimes harms the project performance. Raz and Globerson (1998) note that too much detailed decomposition of the project would eventually increase the workload on the project manager and on the project team. On the other hand too simple decomposition will lead to poor control of the project. According to Bachy and Hameri (1997), deciding how deep and detail to decompose a project is the most important issue for constructing policy guidelines throughout the project. Literature and experience tells us large-scale projects can form as little as five levels and up to more than ten levels. The number of levels and branches differ from project to project, however they are related.

2.3.4. How to create a WBS

There are several ways to create a WBS. PMI (2008) guides project managers to use (1) project scope statement, (2) requirements documentation, (3) organizational process asset as an input and use decomposition technique, resulting a WBS, a WBS dictionary, etc. as figure 3(a). Bachy and Hameri (1997) suggests building a WBS using a Product Breakdown Structure (PBS) and an Activity Breakdown Structure (ABS), where an ABS originates from a PBS as figure 3(b).

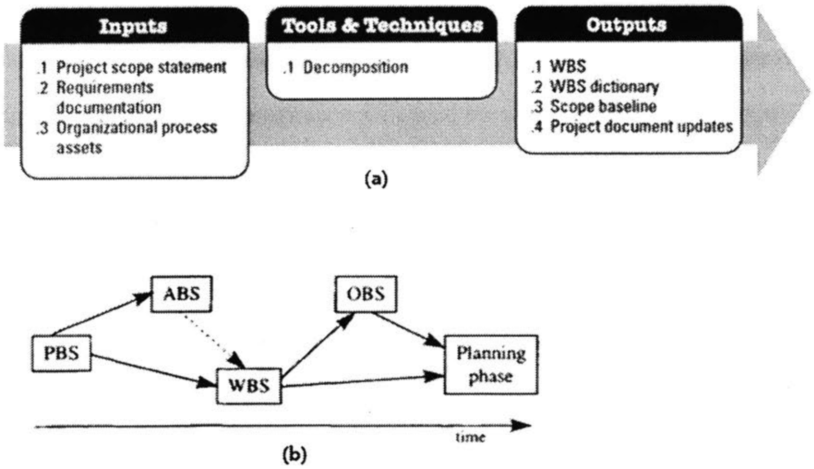


Figure 3. (a) Creating a WBS from PMI (2008), (b) Main Procedure to Establish Project Management Plan from Bachy and Hameri (1997)

Based on the inputs, the first level in the WBS hierarchy starts with the final project deliverable. The final deliverable is decomposed to smaller components until it comes down to work packages. Various breakdown rules are used for decomposition at each level and according to the detail of the work package the breakdown level may differ.

Tonder and Bekker (2002) proposed a method for the development of a deliverable-based WBS from a functional analysis of the project's ultimate deliverable. They first start with identifying the need and a preliminary high-level feasibility analysis. Then analysis for requirements throughout the total product life cycle is performed. These requirements are then used to define the system in functional terms which is "action-oriented". By grouping similar functions together into logical subdivisions and identifying the major subsystem, they synthesized the functions and allocated the deliverables to the functions.

Colenso (2000) identified steps for creating a deliverable-based WBS and a life cycle-based WBS. For a deliverable-based WBS, first put the committed deliverable as level 1 entry. Second, decompose level 1 into their component parts where logical distinction is maintained between components. And decompose it until appropriate level is reached. Third, check if there are any missing deliverables. Fourth, level the hierarchy to the extent that it is possible. Fifth, validate the WBS using a bottom-up approach. Lastly, re-evaluate the entire WBS. For a life cycle-based

WBS, first use major phases from the life cycle as level 1 entry. Second, place the deliverables within the phase where they will be created. Lastly, decompose as in the deliverable-based WBS. From Colenso's approach, Ibrahim et al. (2007) developed a semi-automatic development of a WBS. They started from selecting the decomposition criterion for level 1. After the first decomposition, each WBS element at the second level is decomposed into third level based on a selected criterion. This process continues for until it reaches an appropriate level of detail. The last WBS elements, work packages will be evaluated by the size and content in order to measure the effectiveness of project control.

2.3.5. Function of a WBS

A WBS has a high impact to the project's success. "A WBS organizes and defines the total scope of the project, and represents the work specified in the current approved project scope statement." (PMBOK GUIDE – Fourth Edition) Globerson (1994) refers WBS as a backbone of the proper planning, execution and control of a project. A WBS also clarifies the reporting progress, cost and schedule estimation. Hall (1993) reports on the successful completion of a large-scale project in the range of $225 million, and claims that a major contributor to its success was appropriate use of a WBS.

A WBS provides a clear understanding of the work, process, and the whole project for not only project manager but also to stakeholders and other participants. It decomposes the project chunk into manageable, definable work packages. A WBS shows a framework for the project deliverables over the life cycle of the project. It also facilitates the communication between people and clarifies the responsibility and accountability of the work (PMI 2006). WBS can be connected to the OBS and Responsibility Assignment Matrix (RAM) and concrete the accountability of the project works.

Norman and Brotherton (2008) also agree to the importance of a WBS and introduce some related writings. Homer and Gunn (1995) mentioned "the intelligent structure of work breakdowns is a precursor to effective project management". Kerzner (1997) also mentioned that "a WBS provides the framework on which costs, time, and schedule/performance can be compared against the budget for each level of the WBS". Pritchard (1998) note that "WBS serves as a framework for the development of project plan. It supports all basic components as they are developed and built". Haugan (2002) comments "the WBS is the key tool to assist the project manager in defining the work to be performed to meet the objective of a project". While analyzing why large public projects fail, Holgeid and Thompson (2013) highlight the importance of dividing large efforts into manageable pieces according to risk profile. And in order to mitigate the potential pitfall and to improve performance, Sạfakish (2010) emphasizes the need of an effective work packages. Inadequate design and poorly developed WBS is likely to put a project into a failure (Norman et al., 2008).

Jung and Woo (2004) suggests calculating the workloads such as the number of control account, budget account and operation account by using flexible WBS. They argue that this could be used for determining the overhead efforts for integrated cost and schedule control. Tonder and Bekker (2002) analyzed the possible effect their WBS development method could have on the success of a project by doing a qualitative and quantitative analysis. The analysis was done by listing a set of project success measures that can be influenced by the WBS, and by answering the questions that can be used to analyze the effect a WBS might have on the outcome of a project. These questions were translated from the project success measures. The project success measures they used were estimation of the project complexity, requirement management, project scope clarity, estimations, project planning and scheduling, resource availability, availability of technology and expertise, systemic nature of projects, and task definition. These measures were turned into WBS measurement questions such as does the WBS facilitate the accurate identification of the project complexity, does the WBS accurately reflect the solution to the client's needs, does the WBS structure help in improving the estimation of duration and cost of the project, is the WBS functionally complete, does the WBS include all work packages, does the WBS facilitate the more accurate identification of the resources, does the WBS and the WBS development method reflect the systemic nature of the project, etc. Their result showed their method of developing a deliverable-based WBS has a positive effect on some project success measures.

Chua and Godinot (2006) propose to use the work breakdown structure concept to improve work interface management. First, by crossing a horizontal breakdown of production activities with a vertical breakdown of final products, thus obtaining a WBS matrix, they mapped into interface management and looked if it can improve project performance. They found that WBS matrix was able to eliminate the gray areas in the interfaces, and was able to clarify the interface definition and ambiguous allocation of responsibilities. Also work performance was improved due to the increase in transparency of project requirements and deliverables for each work package.

Globerson (1994) looked at the different WBS patterns and their impact. He noted different WBS patterns call for different organizational structures and management styles during project implementation. An unbalance between the project WBS, the organizational structure, and the management style would lead to poor performance or to project failure. Golany and Shtub (2001) also argued the design of the WBS at the early stage of the project life cycle may have a significant impact on the project success. The WBS designer can change the fundamental structure of the project by choosing different breakdown rules. Tonder and Bekker (2002) looked deeper and depicted a number of organizational factors that influence the WBS development. Those factors are project management maturity of the organization, experience of the team, availability and accessibility of relevant project history, number of successful similar project, and familiarity of the project environment to the project team.

Yuan et al. (2008) argues risk identification as a significant process for the PPP project. According to Yuan et al., WBS can be used for identifying risk. One of the risk identification methods is WBS-RBS method, which is combining WBS with the risk breakdown structure.

Golany and Shtub (2001) talks about the relationship between the project organization and the work breakdown structure, and how this is related to the functional aspect of WBS. By intersecting the WBS and OBS, each work package of WBS can be allocated to each team or individual of OBS. This allocation of work package to the organization unit is essential for project planning, responsibility control, and accountability control.

2.3.6. What is a Good WBS

Some papers discuss about the quality of WBS, so called a "Good WBS". The PMI's Introduction to the Practice Standard for Work Breakdown Structures (2nd Edition) denotes two quality principles for the WBS.

- "A quality WBS is a WBS constructed in such a way that it satisfies all of the requirements for its use in a project" (p. 19)
- "WBS quality characteristics apply at all levels of scope definition" (p. 22)

PMBOK Guide (3rd Edition) also defines the quality as "the degree to which a set of inherent characteristics fulfills requirements". Taylor (2003) mentions that a well-designed WBS should be able to show the planned outcomes, such as product or service, not the planned actions. This is because outcomes are much easier to predict accurately. A well-designed WBS also makes it easy to match each activity to each work package. Norman and Brotherton thought about the intended needs that differentiate one WBS to another and introduced a concept of WBS Use-Related Characteristics for constructing quality WBS. According to PMI, Use-Related Characteristics include those additional attributes that vary from one project to next, across industries, environments or in the way the WBS is applied within the project. By applying the Use-Related Characteristics, the quality of the WBS depends on how well the work packages account the needs of a project. If more needs are met with a particular WBS, then it could be interpreted as the higher quality it has compared to other WBSs. Some of the examples of the Use-Related Characteristics are,

- Achieving a sufficient level of decomposition that enables effective management
- Providing sufficient detail for clear understanding of the project

- Contains feasible mechanism for assessing performance and progress
- Contains specific kinds of WBS elements that are needed for the project
- Clear identification of accountability at the appropriate level

Since the Use-Related Characteristics change from project to project with different needs, there is a correlation between a good quality WBS and the fulfillment of the project's needs (Norman and Brotherton, 2008).

2.4. Product Breakdown Structure

Studies regarding WBS show many possibilities in the integration with other breakdown structures for various functional aspects. One of the breakdown structures is the Product Breakdown Structure (PBS). This section will cover the definition of a PBS and its relationship to a WBS.

2.4.1. Definition

PBS is a hierarchical structure that decomposes a product by sub-components. It illustrates the physical components of a particular product, or system in a structural manner. It begins with the final product at the top of the hierarchy followed by the sub-categorized elements of the product. According to Bachy and Hameri (1997) a PBS is used for controlling material, production and information in most companies with discrete production facilities. Each chunk in the product structure hierarchy includes instructions on manufacturing and quality control, technical description of the elements, etc.

The PBS is essentially the breakdown structure of a product into its required components. The purpose of this breakdown is to provide a visual representation of a products components and the relationship between those components. In turn, product planners are provided with a visual representation that provides clear understanding for what the end product requires.

2.4.2. Relationship to WBS

Similar to a WBS, PBS serves to reduce a complex project, or product, into manageable components so that teams can obtain a clear understanding of a product and its components. The main difference between a PBS and WBS is that a PBS only includes the physical elements of a product. A WBS, on the other hand, incorporates the necessary data and service elements along with the physical product elements that a PBS provides. As a result, if a WBS is decomposed based on only functional, or deliverable-oriented rule, the final work package will be almost same as the final elements of PBS. In many cases PBS is used as a first step to create a WBS. By clarifying the product's basic elements, it is easy to develop work needed and the cost, schedule etc. Lamers (2000) note that the proper way of creating a WBS is, "first the definition of the product, then the definition of the processes required to generate the product, then the control of those processes, and only then the organization to exercise the processes and their control with".

Chua and Godinot (2006) used a WBS matrix to improve interface management by crossing a PBS and ABS (activity breakdown structure). He et al. (2011) tried to create a WBS by transforming data from a PBS to WBS.

2.5. Organizational Breakdown Structure (OBS)

Project manager can derive the important project elements such as cost, schedule, responsibility etc. by matching a WBS with an organizational structure. Since an organizational structure and OBS is highly related to the WBS and to the project performance, this sector will review the types of an organization structure, definition of an OBS, and its relationship with a WBS.

2.5.1. Organizational Structure

Enterprises structure their organization in order to maximize the efficiency of the work and to minimize the potential conflict. The best known types are functional, matrix and project-based organizations (Stare, 2011). The functional organization is suitable when the division of tasks is clear and the tasks are repeatable. It is a hierarchical structure where organization units are distinguished by their functional roles (Golany and Shtub, 2001). According to Stare (2011), efficiency and effectiveness of the work would be high in functional organization since the units are grouped by similar function and resource. Furthermore, there is a synergy effect within the unit due to the easiness of sharing experience and skills. A disadvantage of this structure is that it is not flexible enough for complicated projects. Complicated projects need a lot of communication and collaboration between organization units. However, since the units in functional organization are grouped into similar functions, the information flow between other units is difficult. Furthermore, in case of projects where there are multiple stakeholders, communication between the stakeholder and specific organization unit is difficult because functional organization does not have single point of contact. According to Stare (2011), employees in functional organization has their daily routine work, thus are required to do extra works for a project. He depicts the firmness as an advantage of this organization. Since all the works regarding the project are additional tasks, new project would not change the existing structure. The disadvantage of functional organization is that team members always give priority to their usual or functional duties.

The project structure is designed to assign a project to a single team. The organization is made of teams that perform different projects. The members of the project team may have different skill, background, and education. After the project is done, the team members may separate and belong to another team. Golany and Shtub (2001) note that the advantage of the project structure is its flexibility; "the project team can be assembled exactly according to the task at hand". Another advantage is the member's commitment to the work. Unlike functional organization, team members in project organization do not have any daily routine tasks. They can solely focus on the project. Also since the project is handled by a single team, the single point of contact gives a great advantage to both program manager and stakeholders. "Teamwork and coordination between people coming from different disciplines are easier to achieve when they belong to the same project." (Golany and Shtub, 2001) The disadvantage of this structure is that compared to the functional organization, the efficiency and effectiveness of the work is hard to get. Also in large-size projects where many parties are involved and precise allocation of work is needed, the project organization has a disadvantage due to the problem of division of labor. In large-size complex projects, the integration of works from different units or parties is essential.

The project matrix structure is a combination of the functional and project structures. Employees usually work on their daily routine task, but also can be assigned to a team for a specific project (Stare, 2011). A team consists of members who are employed full time by the project and other members that belong to a functional unit and members who are employed part time on one or more projects is assigned to the projects. The matrix organization improves workplace communication from the top down and across departments. It also boosts team concept. The disadvantage is that employees have to report to two managers, typical functional manager and project manager. And there could be a conflict of priorities amongst different projects.

Functional, project, matrix organizational structure exist throughout the industry, however typically in many PPP projects, the nature of the organization is not flexible.

2.5.2. Definition of OBS

An Organizational Breakdown Structure (OBS) is a model that describes a framework for organizing resource and tracking time and expense. An OBS relate the work packages to the organizations structure. An OBS is useful in tracking the team, individual, and work allocation (Abbasi et al., 2000). It is also used to define the responsibilities for project management, cost reporting, accountability and project control. An OBS provides an organizational view of the project such as who is doing the work and who are working together, rather than product view or activity view. An OBS provide valuable information for project management when combined with other breakdown structures. "When project responsibilities are defined and work is assigned, the OBS and WBS are connected providing the possibility for powerful analytics to measure project and workforce performance at a very high level" (Tenrox, 2018).

2.5.3. Relationship to WBS

In many practice, an OBS is derived from the information of a WBS and an ABS. However, a WBS and an OBS influence each other in order to specify project planning. The decisions for the decomposition and the formation of a WBS directly influence the organizational structure of the project. (Bachy and Hameri, 1997). When designing a WBS, it should be related to the organizational structure for better understanding of the term and execution. "If the organization is structured in a particular functional manner, the WBS should be similarly formulated" (Globerson, 1994). Badiru and Pulat (1995) also note that there is a strong interdependency between an OBS and a WBS.

When a WBS is decomposed with a resource-oriented or organizational unit-oriented, it is likely to correspond with the OBS. In that case tasks related to the organizational structure may have better management during the project progress.

2.6. Design Structure Matrix (DSM)

In the last three sections, the relationships between a PBS, OBS, and WBS were reviewed. These relationships can be more easily understood when look at the interactions between each element. DSM is a good tool for representing the interactions between elements. This section will cover the definition and the methodology of DSM.

2.6.1. Definition

The term DSM was coined by Steward (1981) as he first applied the matrix format to solve mathematical equations. According to Eppinger and Browning (2012), "The DSM is a network modeling tool used to represent the elements comprising a system and their interactions, thereby highlighting the system's architecture. DSM is particularly well suited to applications in the development of complex, engineered systems and has to date primarily been used in the area of engineering management". The DSM has a form of square matrix. Elements that form a system are labeled along each side of the matrix. And whenever there is an interaction between two different elements, a mark is made in the intersection. This mark could be represented simply by "x", which means there is an interaction, or by different sizes of circle, which shows the frequency of the interaction, or also by numbers. Eppinger and Browning (2012) developed the DSM to represent various types of architecture. They introduced a way to represent a product architecture DSM, an organization architecture DSM, a process architecture DSM, and multi-domain matrix (MDM). To represent product architecture, product components were positioned along each side of the DSM. If there are interactions between the components, a mark is made in the intersection. For organization architecture DSM, organization units or teams were used as the elements and the communications between these units were marked in the intersection of the matrix. In process architecture DSM, they used activities required for the system as elements of DSM. Flow of information was thought as an interaction between activities and was marked in the intersection of the matrix. The three types of simple DSM example for an airplane system are depicted in figure 4.

interactions between components	cockpit	fuselage	engine	f. wing	t. wing	wheel	tail
cockpit		x					
fuselage	x			x	x	x	x
engine				x			
front wing		x	x				
tail wing		x					
wheel		x					
tail		x					

(a) Product Architecture DSM of an Airplane System

communications between org. units	pilot	control tower	other pilot	maintenance	flight crew	passenger
pilot		x	x	x	x	x
control tower	x		x	x		
other pilot	x	x				
maintenance	x	x				
flight crew	x					x
passenger	x				x	

(b) Organization Architecture DSM of an Airplane System

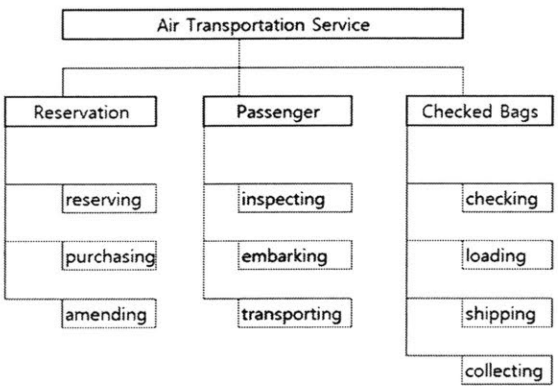
information flow between processes	start engine	function checking	stand by airstrip	take off	flying	landing	maintenance
start engine		x					
function checking	x			x	x	x	x
stand by airstrip				x			
take off		x	x		x		x
flying		x		x		x	x
landing		x			x		x
maintenance		x		x	x	x	

(c) Process Architecture DSM of an Airplane System

Figure 4. Three types of simple DSM model of an Airplane System

In figure 4(a), product architecture DSM shows how components of an airplane are linked together. Cockpit, both front and back wings, tail and wheel are connected to the fuselage. Engine is connected to the front wing. These interactions are presented by mark "x" in each intersection. Figure 4(b) shows the communications between each organization units. Here you can see the communication frequency or density between pilot and control tower, maintenance, etc. Likewise, activities that are need for the airplane system and their flow of information are depicted on figure 4(c). However these three examples of DSMs are not clustered yet.

The marks on the DSM help you to understand the interaction between components quite intuitively. However you could get more valuable information from clustering the elements based on DSM. Clustering a task of grouping elements in a way that particular group have more similarity than others outside the group. So through clustering the elements based on the DSM, elements can be organized by the connectivity or the frequency of interactions. As clustering shows how elements with similar interactions are grouped together, these clusters are also reflected in the product, organization, or process structure. Figure 5 shows different structures for a same air transportation service (Crawley et al., 2016). Figure 5(a) is a process breakdown structure, (b) is an un-clustered process architecture DSM, (c) is a clustered process architecture DSM. Before clustering, alignment cannot be found between figure 5(a) and (b). However after clustering by the interaction between processes, it shows the similarity of grouping between (a) and (c).



(a)

Unclustered DSM	reserving	departing	checking	purchasing	shipping	embarking	amending	arriving	loading	collecting
reserving	4	1	3	3	0	1	4	1	1	2
departing	1	4	1	1	1	3	1	4	1	2
checking	3	1	4	3	0	1	3	1	1	3
purchasing	3	1	3	4	0	1	4	1	1	2
shipping	0	1	0	0	1	0	0	1	1	1
embarking	1	3	1	1	0	4	1	3	0	1
amending	4	1	3	4	0	1	5	1	1	2
arriving	1	4	1	1	1	3	1	4	1	2
loading	1	1	1	1	1	0	1	1	2	2
collecting	2	2	3	2	1	1	2	2	2	4

(b)

Clustered DSM	reserving	purchasing	amending	arriving	embarking	departing	checking	loading	shipping	collecting
reserving	4	3	4	1	1	1	3	1	0	2
purchasing	3	4	4	1	1	1	3	1	0	2
amending	4	4	5	1	1	1	3	1	0	2
arriving	1	1	1	4	3	4	1	1	1	2
embarking	1	1	1	3	4	3	1	0	0	1
departing	1	1	1	4	3	4	1	1	1	2
checking	3	3	3	1	1	1	4	1	0	3
loading	1	1	1	1	0	1	1	2	1	2
shipping	0	0	0	1	0	1	0	1	1	1
collecting	2	2	2	2	1	2	3	2	1	4

(c)

Figure 5. (a) Process Breakdown Structure of an Air Transportation Service, (b) Un-clustered Process Architecture DSM of an Air Transportation Service, (c) Clustered Process Architecture DSM of an Air Transportation Service (partial use from Crawley et al., 2016)

This gives us a valuable lesson. If the elements of a structure are clustered in a certain way, the final structure will highly align with a structure that is decomposed by similar breakdown rules. This clustering notion will give us a sense on how to efficiently group work packages later on.

According to previous WBS literature review, a WBS has close relationship with a PBS and OBS. It will be useful to look more into the product DMS and the organization DSM.

2.6.2. Product Architecture DSM

Product architecture DSM is a matrix that shows the elements of the product, usually component, and their interactions. These interactions could be interface, dependency, etc. Eppinger and Browning (2012) note that "using product architecture DSM models, many researchers and industrial practitioners have been able to better understand networks of interactions in complex systems, yielding two primary types of benefits". They refer two types of benefit as architecture and integration. An assessment of the match between technical and organizational architectures is one of the architecture benefits.

Eppinger and Browning introduce a simple way of clustering the elements in the matrix, by shifting the rows and columns so that the size of the cluster and the number of the marks outside the cluster can minimize. A good clustered product DSM would show components which have similar or high interactions are gathered together. If the product is complex enough, the second level clustering can be done. This bottom-up approach will make a hierarchical structure, and it will be highly aligned with a PBS, where product is decomposed by the components level by level. Eppinger and Browning show several ways to cluster as figure 6.

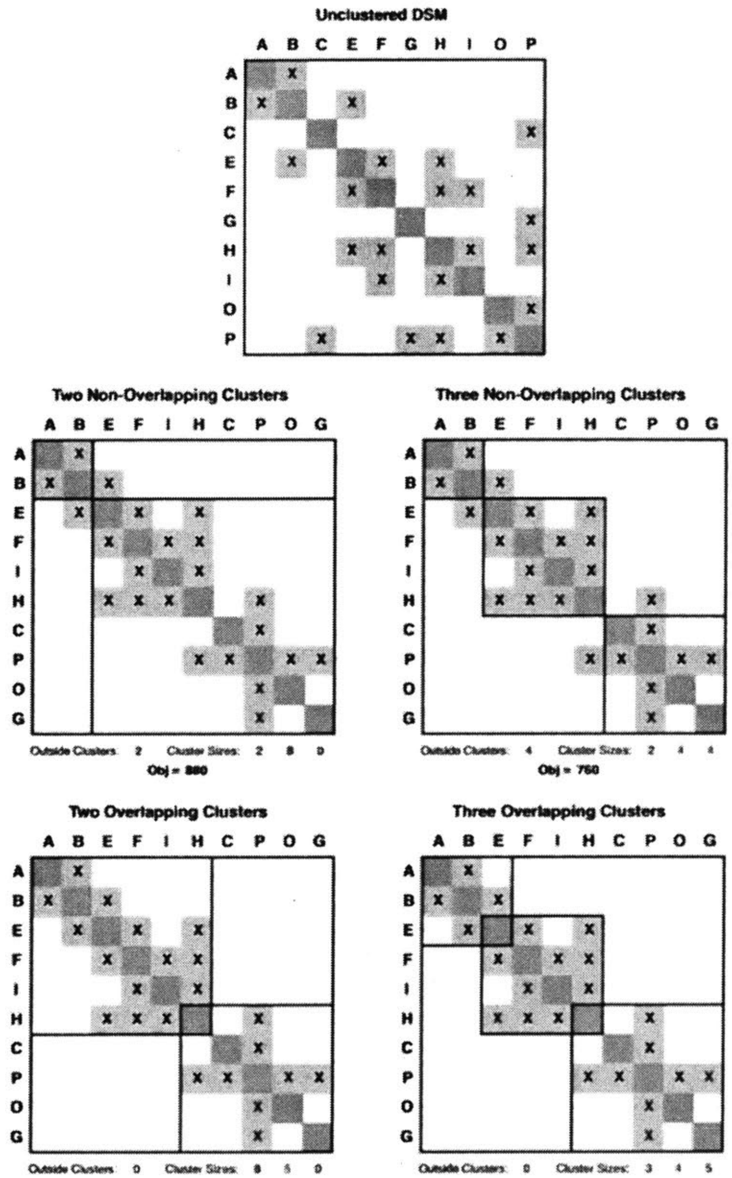


Figure 6. DSM before and after clustering (Eppinger and Browning, 2012)

2.6.3. Organization Architecture DSM

The important mechanism of organization architecture is to structure an organization so that the units, usually individual or team could communicate, collaborate, and conquer the work efficiently. As depicted in the literature review of an OBS, the key decomposition rules used there were function of the unit, allocated project, etc. However in an organization architecture DSM, the information flow between the units are considered. Information flow captures how certain information that has impact on after task moves from unit to unit. By putting the units along each dimension and marking in the intersection of two units, organization architecture shows the relationship between each unit. When units are clustered by the intensity of information flow, such organization will have high efficiency in the context of schedule and performance then other organizations.

2.7. Domain Mapping Matrix (DMM)

The DSM captures the interactions between elements within the same architecture. Its limit is that it cannot show the relationship with the elements in other domains. On the other hand, Domain Mapping Matrix is a matrix that maps two DSM from different domain. DMM shows the interactions between the elements of two different domains. Since the number of elements in each DSM may differ, DMM commonly form a $n \times m$ rectangular matrix. Figure 7 shows an example of DSM. From the example of airplane system above, product DSM and process DSM are at each left-upper side and right-lower side. The right-upper side 6×7 matrix shows an interactions between elements of product DSM and elements of process DSM. For example, pilot involves in starting engine, function checking, standing by airstrip, etc. maintenance mechanic involves in function checking and maintenance.

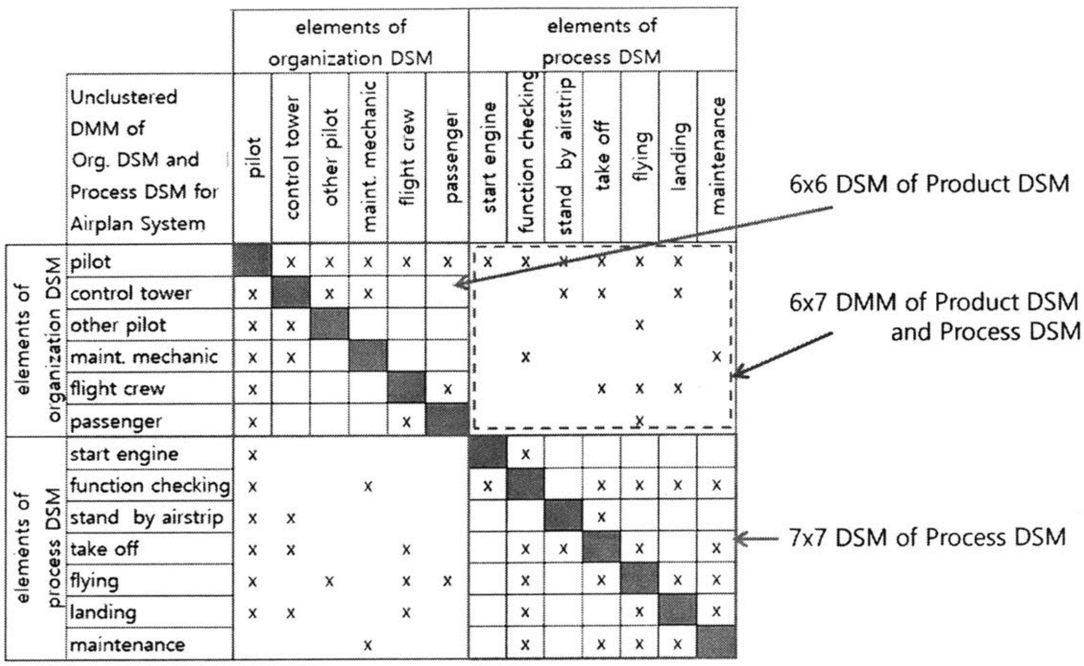


Figure 7. DMM of Product DSM and Process DSM for Airplane System

Elements of DMM can also be clustered. Grouping elements by the interactions can highlight which units are worked together for same purpose, which components are managed by same team, etc. Figure 8 shows a simple clustering of the DMM from figure 7. After clustering, it is more visual that flight crew, pilot, and control tower have strong interactions during the stand by, take off, and lading processes. During flying process, most of the organization units are involved. Maintenance can be worked alone expect function checking with pilot. Also since the DMM are usually rectangular matrix, compared to the clustering from the DSM, clusters appear anywhere in the matrix. Eppinger and Browning also mentioned about the blank areas where there is no relationship between domains. "This implies that we might be missing some important information from the customer requirements, or that we might have introduced some superfluous product specifications", Eppinger and Browning (2012).

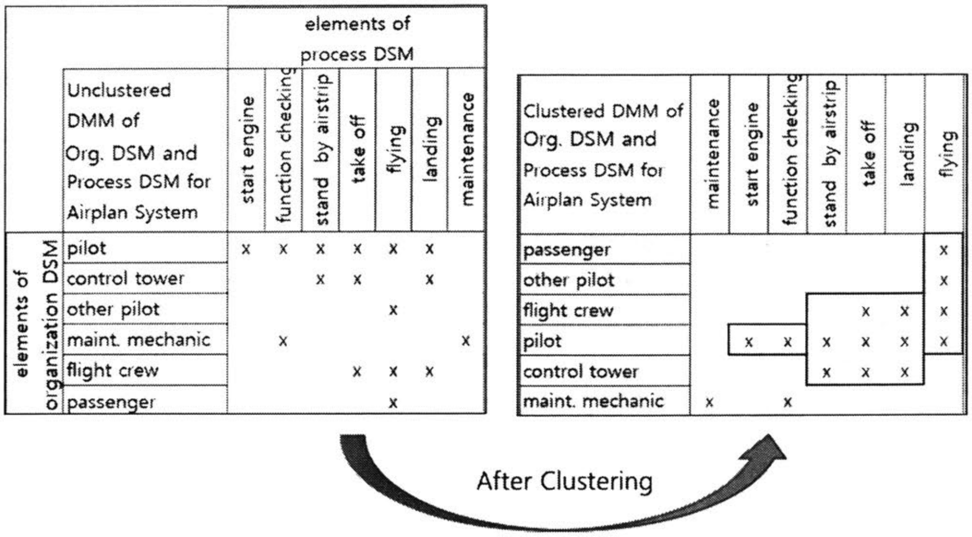


Figure 8. DMM before and after clustering

DSM and DMM visually show the interaction between elements, within and across the domain respectively. This concept might be useful when comparing the degree of an alignment between a WBS and a PBS, and between a WBS and an OBS. The clustering technique that was used in DSM and DMM help us understand how the elements should group together for better performance. This logic can be used later on in grouping the work packages into breakdown rules.

2.8 Summary

The motivation to seek a better way to improve performance in Public-Private Partnership project led to questions like "What are the types and characteristic of breakdown rules of WBS?", "How does different WBS give impact to the performance of PPP project?" In order to get answers and insights, related literatures were reviewed. PPP is different from conventional contract in the aspect of risk sharing and the nature of long-term, large-size complicated projects. PPP projects benefit from better cost certainty, schedule certainty, and quality through the use of more refined and innovative construction methods when compared to more traditional methods of project delivery. There are many important factors that lead to the success of PPP projects, such as appropriate risk allocation and sharing, political support, transparent procurement, technology innovation, etc. Some of them (e.g. financial feasibility) need to be resolved in the very early phase, some (e.g. political support) are hard to resolve. However some factors (e.g. detailed project planning, constant communication, etc.) can be managed well with a proper project management. Also research depicts the importance of project planning phase. They agree that the planning phase has the most influence on the project's success. And among the actions in project planning phase, many literatures emphasize the importance of building WBS. Researchers note that WBS is the most important task for the proper planning, execution and control of a project.

WBS is a structure that illustrates the project how they are broken into small chunks of manageable works. These final elements are called work packages and they tell us where the responsibility of the work lies and which work can be further planned independently. A breakdown rules are the decision criteria for decomposition. There are several types of breakdown rules, and the most commonly used ones are Functional, Phase, Geographical, Resource, and Activity based breakdowns. Researchers agree that different breakdown rule for each level has different impact on the organization, product, and process structure which are related to the project requirements. Especially they depict the strong relationship between breakdown rules and organizational structure. However studies regarding comparing the effects of different breakdown rules and selecting which one to use were insufficient. The level of decomposition was also reviewed. An over detailed breakdown leads to extra administrative work, and one too loose often leads to poor control of progress and costs. Several papers have studied how to make WBS and some have looked into the breakdown rules. Current literatures introduce good tips and ideas for using an appropriate breakdown rule for different kind of projects; however, most of them propose a process of creating a single WBS and does not have a concrete guidance. Tonder and Bekker (2002) also agree on that there is no concrete guidance regarding the definition and appropriate level of the deliverables. Functional aspect of a WBS was also reviewed. WBS provides the framework on which costs, time, and schedule/performance can be compared against the budget for each level of the WBS. Jung et al.

(2004) proposed using flexible WBS to calculate the workloads and determine the overhead efforts for integrated cost and schedule control. Tonder et al. (2002) introduced a method for the developing a deliverable-based WBS and analyses the possible affects it could have on the success of a project. Chua and Godinot (2006) proposed a way to use the WBS concept to improve work interface management. Considering the functional aspect, a good WBS must satisfy all of the requirements of the project at any level.

As creating a WBS was highly related to a PBS and OBS, a PBS and OBS were also reviewed. In many cases a PBS is used as a first step to create a WBS. By clarifying the product's basic elements, it is easy to develop work needed and the cost, schedule etc. There are three types of organizational structure; functional, matrix, and project-based. In a functional organization, the role of each organizational unit is to deal with the work content related to its function, as a result efficiency and effectiveness can be easily achieved, and experience can easily be shared. However it is not flexible enough when dealing with complex tasks. Complex tasks need a lot of communication between departments, however in a functional organization this cross communication is hard to achieve. Also stakeholders may have difficulty when they need to communicate with a department due to multiple contact points. On the other hand, project-based organization is designed to handle one-time, unique, and non-recurrent endeavors. It has high flexibility and single contact point but is hard to achieve efficiency and effectiveness due to its temporary nature. In the aspect of the relationship between an OBS and WBS, literatures show that WBS should fit the organizational culture and structure so that the vocabulary regularly used in the organization can also be used for the project.

In the review of DSM and DMM, Eppinger and Browning (2012) show how hierarchical breakdown structures can be expressed through lateral matrix way and vice versa. Using the technique of DSM and DMM, elements can be clustered with various criteria so that the system can easily correlate with other systems. For example, by clustering the WPs, final elements of WBS, in a different rule, the correlation of WBS to other breakdown structures will change. If WPs are clustered by the DMM between WPs and the final elements of PBS, then the WBS will have high correlation with PBS. Likewise, if WPs are clustered by the DMM between WPs and the final elements of OBS, then the WBS will have high correlation with OBS. This high correlation means that related tasks or requirements will be managed efficiently or has high performance when WBS is used.

3. Research Approach & Hypothesis.

With all the literature review, it is affirmative that creating a good WBS will improve the performance of project in PPP. However current literatures mostly introduce ways to create a single WBS. And studies that compare the effect of using different breakdown rules to the project performance are hardly done. If we can develop a method that can create several WBSs having different combination of breakdown rules for the same project; if we can compare what effect of each breakdown rules have on the requirement and situational factors of the project; and if we can measure the alignment between a WBSs and an OBS/PBS and compare the results with above effects, it will be possible to obtain a set of optimized WBSs that maximize performance on the requirements maintaining balance. With several options for WBSs along with their different effects, various partners in dialogue can shape their work approach efficiency in the early phase.

This paper aims to propose a new method called the Work Breakdown Design Pattern Generator which can forecast different performance given WBSs designed through different combinations of breakdown rules, and show the variation in alignment across breakdown structures. The Work Breakdown Design Pattern Generator will help us design a WBS based on the ability to compare alternatives and their potential benefits. To address the problem statement and research objectives described as above, the following hypotheses are established

HP1. For a project, the change in the breakdown rules lead to different emergent project architectures.

HP2. For a project, different architectures have different performances that are judged by requirements.

HP3. For a project, a WBS that is made of a specific combination of breakdown rules which perform well on requirements related to PBS/OBS will have high alignment with that breakdown structure.

To approach this problem several system thinking principles and techniques will be used. First, with the properties of architectural decisions and metric, a WBS will be analyzed to create a morphological matrix for the Work Breakdown Design Pattern Generator which includes architectural decisions and their options. With the evaluation metric and scoring process, the results will be visualized and analyzed through tradespace analysis. The alignment between WBSs and PBS/OBS will be measured using DMM properties. The alignment and the scenario analysis will be used to validate the Work Breakdown Design Pattern Generator.

4. System Thinking Principles & Techniques

This chapter introduces four system thinking principles and techniques which will guide us throughout the design, analysis, and validation of the Work Breakdown Design Pattern Generator.

4.1. Principle of Balance

"Many factors influence and act on the conception, design, implementation, and operation of a system. One must find a balance among the factors that satisfies the most important stakeholders." (Crawley et al., 2016)

There is always a tradeoff between meeting requirements when designing a system. One example is the iron triangle. In most projects scope, cost, and schedule are in conflicting position. If you try to reduce one side, others get affected in opposite ways. Sometimes, even within a subsystem, different functions conflict each other and must be balanced. Typical characteristics of PPP project are the multiple stakeholders and the complexity of the project. So the important role of a project manager is to well balance the requirements so that the stakeholders will be satisfied with the outcome. These requirements are projected into the product and the operation of the organization. As a result, in the project planning phase, a WBS must be created in a way that its structure balances well with the product and organization structure.

4.2. Principle of Decomposition

"Decomposition is an active choice made by the architect. The decomposition affects how performance is measured, how the organization should be set up, the potential for supplier value capture, and how the product can evolve, among many other things. Choose the plane of decomposition to align as many of these factors as possible, in order to minimize the apparent complexity of the system." (Crawley et al., 2016)

As ancient Romans saying "Divide and rule", dividing a big problem makes things less complicated and easy to tackle. The underlying premise is that complex problems imply many interactions between the elements and affect each other. Dividing the problem into several chunks makes fewer interactions that are easy to solve, eventually guiding us to solve the whole problem. However, dividing randomly does not make the problem solving easier. One must understand the interaction between the elements of the problem and find out which elements are highly connected and which ones are not. Different way of dividing the problem will affect the performance of the problem solving. This is the underlying principle of the Work Breakdown Design Pattern Generator. Project managers usually select the breakdown rules for WBS from past similar projects, commonly accepted criterion, or from just intuition. Many of the times, they put a lot of effort to create a single good (what they believe) WBS. The Work Breakdown Design Pattern Generator creates lots of WBSs and gives the ability to compare alternatives and their potential benefits for breakdown rules.

4.3. Principle of Robustness of Architectures

"Good architectures need to respond to all manner of variations. They can respond to these variations by being robust or being adaptable. Optimal architectures in the Pareto sense are often the least robust. Consider optimality, robustness, and adaptability in the choice of an architecture." (Crawley et al., 2016)

When an analysis values are depicted in the tradespace with a utopia point, a Pareto frontier can be made. The values that are on the Pareto frontier can be thought as to be the most effective values among others since they dominates other values. However, values that are off the Pareto frontier also can be effective value. The values on the Pareto frontier are effective in the context of the utilities for the tradespace axis. If there are any third utility that is as important as the two for the tradespace, the overall performance (or robustness) would be the one off the Pareto frontier.

4.4. Principle of Architectural Decisions

"Architectural decisions are the subset of design decisions that are most impactful. They relate to form-function mapping, they determine the performance envelope, they encode the key tradeoffs in the eventual product, and they often strongly determine cost. Separate these architectural decisions from other decisions, and take the time to carefully decide them up front, because they will be very expensive to change later on." (Crawley et al., 2016)

Architecture decisions are the fundamental decisions that need to be made in order to form a unique system. Even though two systems look alike, if the architectural decisions are different, they are fundamentally different systems. For each architectural decision, there are several options one can choose. These options have tradeoffs in certain way, generally in the context of the requirements of a project. Usually when one architectural decision's option is selected, this affect to other architectural decisions. This is called a constraint. And the constraints make architectural decisions couple together.

5. Concept of Operations (ConOps)

The concept of operation is a document or a diagram that describes how the system works and how the value is created in the perspective of the user. Through ConOps, people can easily understand the system and its value, and can compare with other systems. In this section, each ConOps for conventional way of creating WBS and for the proposed Work Breakdown Design Pattern Generator are presented using object-process methodology (OPM) diagram.

The conventional ways to create WBS were mostly following the existing WBS from similar project, using project manager's intuition, or using brainstorming starting from none, and coming up with a single WBS. This ConOps is presented in figure 9.

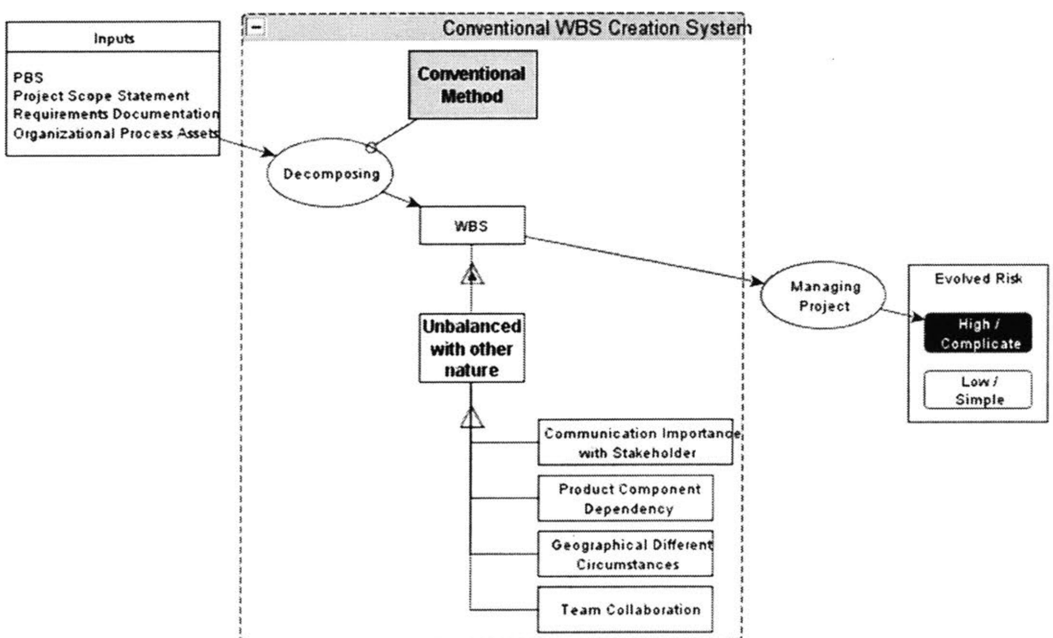


Figure 9. Conventional WBS Creation System Notion

Project managers gather a variety of information, such as PBS, project scope statement, requirement document, assets, etc. to create a WBS. Then project manages decompose the project using the conventional method as illustrated above, and come up with a single WBS for the project. However, that WBS may have some "ill-fitting (or unbalance)" with other nature of the project, such as organizational structure, product structure, etc. As project runs, this ill-fitting can evolve into risks that can result low performance or project failure. Or there might be a better WBS that balances much effectively and has high performance. This is because different breakdown rules used in the high-levels of WBS will bring distinctive performance for each WBS.

The Work Breakdown Design Pattern Generator introduces different way of creating a WBS. The ConOps of the Work Breakdown Design Pattern Generator is shown as figure 10.

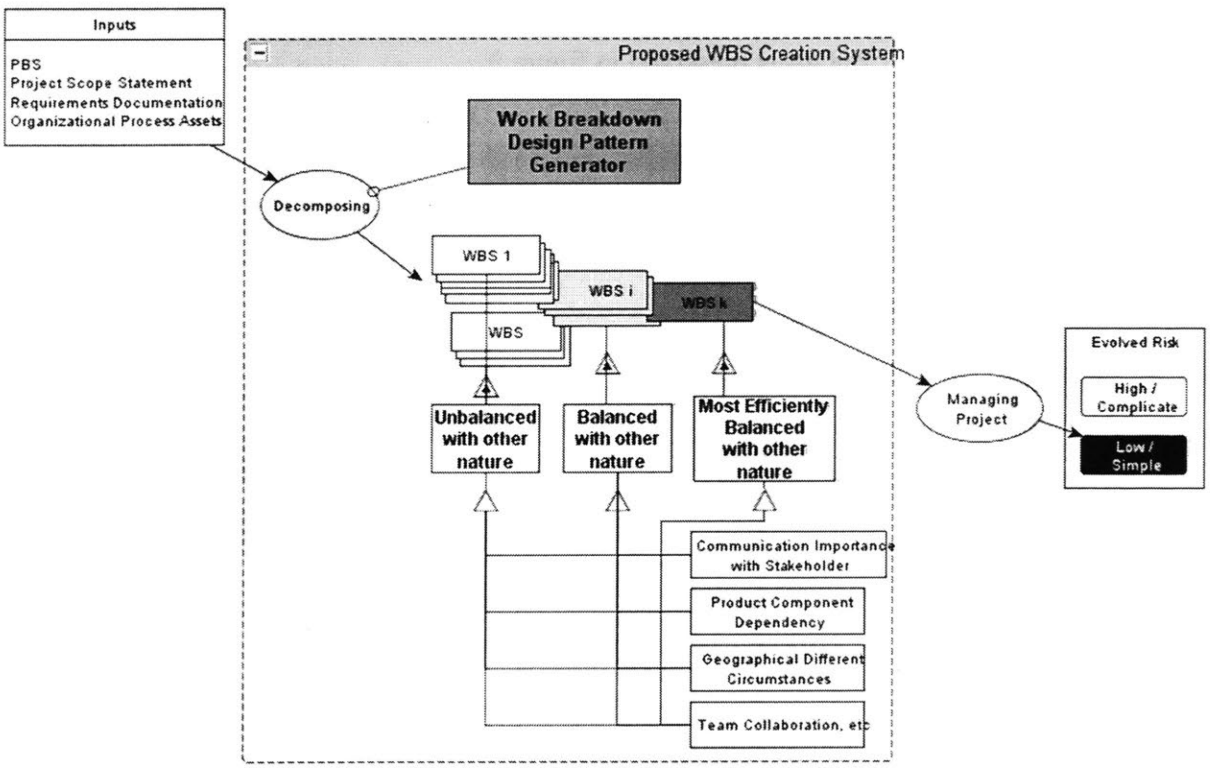


Figure 10. Proposed WBS Creation System Notion

Project managers gather information in a same way as a preparation. Then he uses the Work Breakdown Design Pattern Generator to decompose the project. The Work Breakdown Design Pattern Generator will create many WBSs with the combination of the breakdown rules. Each WBS will have different degree of alignment with PBS or OBS, and will have different performance. These WBSs will be analyzed through tradespace analysis and be shortened down to a set of WBSs that have high performance and balance. Project managers can easily choose a WBS that is most suitable according to the situations of the project.

6. Work Breakdown Design Pattern Generator

Based on the ConOps and system thinking principles shown in previous chapters, this chapter illustrates the architecture of the Work Breakdown Design Pattern Generator. Morphological matrix, alignment between WBS and PBS/OBS, tradespace exploration with an example are depicted in this chapter.

6.1. Context Description

The underlying assumption of the Work Breakdown Design Pattern Generator is that WBSs using different breakdown rules will have different alignment with OBS, PBS etc. This can be shown through comparing the clusters of work packages with the clusters of final elements of OBS, PBS etc. created by DSM and DMM.

6.2. Architectural Decision and Morphological Matrix

The first level of WBS is usually the final project deliverable or outcome. Second level consists of the clusters (work chunks) decomposed by specific breakdown rule. The decomposition will continue until it reaches to WPs. These high-level clusters will be compared with the cluster of OBS, PBS etc. In this paper three levels of breakdown rules will be used as an architectural decision for the Work Breakdown Design Pattern Generator (for the DMM demonstration, only two levels are shown for simplicity). Among many types of breakdown rules that are out in practice, 1) functional breakdown, 2) phase (time) breakdown, 3) resource breakdown, and 2) activity breakdown, which are most frequently used, are chosen as the options for each architectural decision. Table 3 shows the morphological matrix for the architectural decision of the Work Breakdown Design Pattern Generator and figure 11 shows an example of WBS using resource breakdown as level 2 breakdown rule and functional breakdown as level 3 breakdown rule. With the combination of options for two levels, total 64 types of WBSs can be made.

Table 3. Morphological Matrix for Architectural Decision of the Work Breakdown Design Pattern Generator

Architectural Decision	Option1	Option2	Option3	Option4
Level 2 Breakdown Rule	Functional (=Deliverable)	Phase (=Time)	Resource (Organization)	Activity (=Task)
Level 3 Breakdown Rule	Functional (=Deliverable)	Phase (=Time)	Resource (Organization)	Activity (=Task)
Level 4 Breakdown Rule	Functional (=Deliverable)	Phase (=Time)	Resource (Organization)	Activity (=Task)

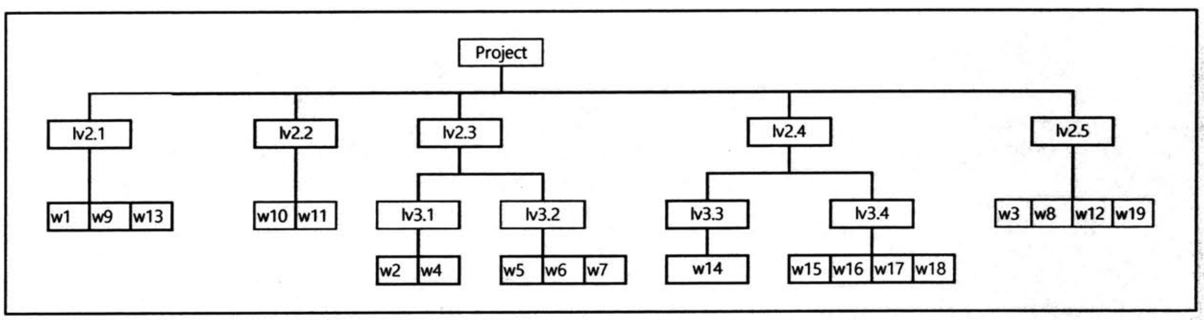


Figure 11. Example of WBS using Resource Breakdown (for Level2) and Functional Breakdown(for Level3)

6.3. Alignment

Organization DSM is made by clustering the final units of OBS using team (or individual) interactions and communications. WBS-OBS DMM is made by clustering the WPs using relationship between WPs and final units of OBS, as shown in figure 12. By comparing the clusters from WBS-OBS DMM and organization DSM with the WBS clusters of level 3 and 2, the degree of alignment between WBS and OBS can be obtained. The alignment percentage can be calculated by the number of work packages aligned of the total number of work packages as table 4.

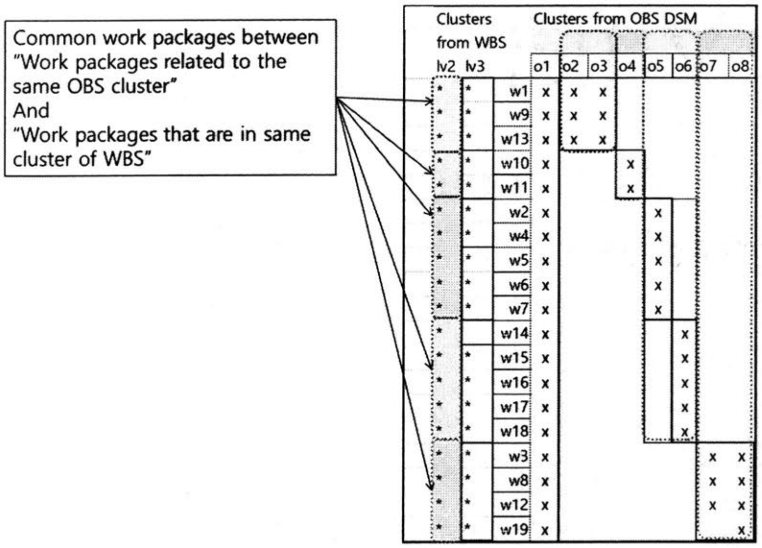


Figure 12. DMM of the WBS(Resource-Functional) and the OBS

Table 4. Degree of Alignment between the WBS (Resource-Functional) and the PBS/OBS

Cluster Level	Alignment%(WBS&PBS)	Alignment%(WBS&OBS)
Level2(Resource)	57.9%	100%
Level3(Functional)	57.9%	94.7%

For simplicity, the degree of alignment based on the value of level 2 will be used in this paper. In above case, when a WBS uses resource breakdown rule for level 2 breakdown, that WBS will have 100% alignment with OBS.

Product DSM is made by clustering the final components of PBS using component dependency. WBS-PBS DMM is made by clustering the WPs using relationship between WPs and final components of PBS, shown as figure 13. By comparing the clusters from WBS-PBS DMM and product DSM with the WBS clusters of level 3 and 2, the degree of alignment between WBS and PBS can be obtained as table 5. In a same way, when a WBS uses resource breakdown rule for level 2 breakdown, that WBS will have 57.9% alignment with PBS.

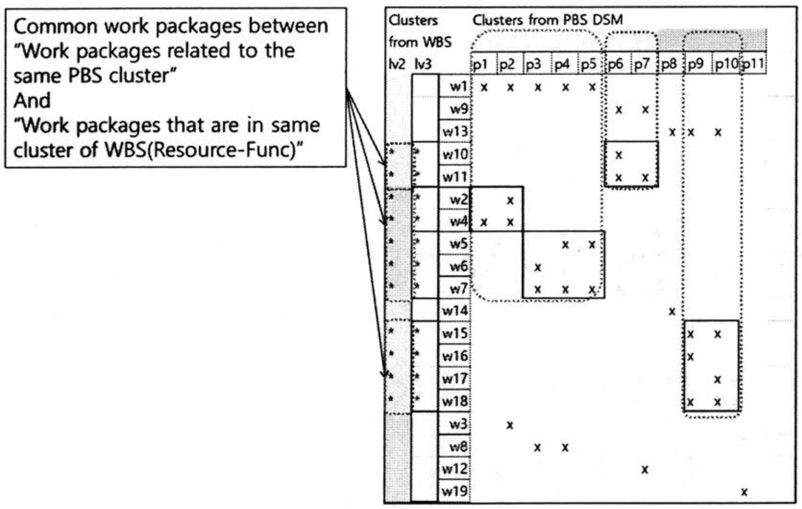


Figure 13. DMM of the WBS(Resource-Functional) and the PBS

Figure 14 shows another example of the WBS using phase breakdown as level 2 breakdown rule and resource breakdown as level 3 breakdown rule. WBS-PBS DMM and WBS-OBS DMM is made by clustering the WPs using relationship between WPs and final units of PBS, and final units of OBS as figure 15. By counting the common work packages between the "work packages related to the same PBS cluster" and "work packages that are in same cluster of the WBS(phase-resource)", the degree of alignment between WBS and PBS, OBS can be obtained like table 5.

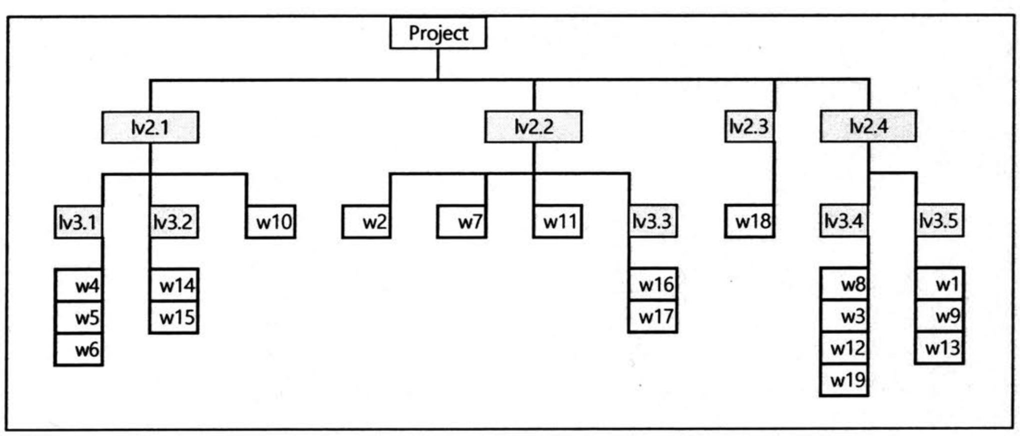


Figure 14. Example of the WBS using Phase Breakdown (for Level2) and Resource Breakdown(for Level3)

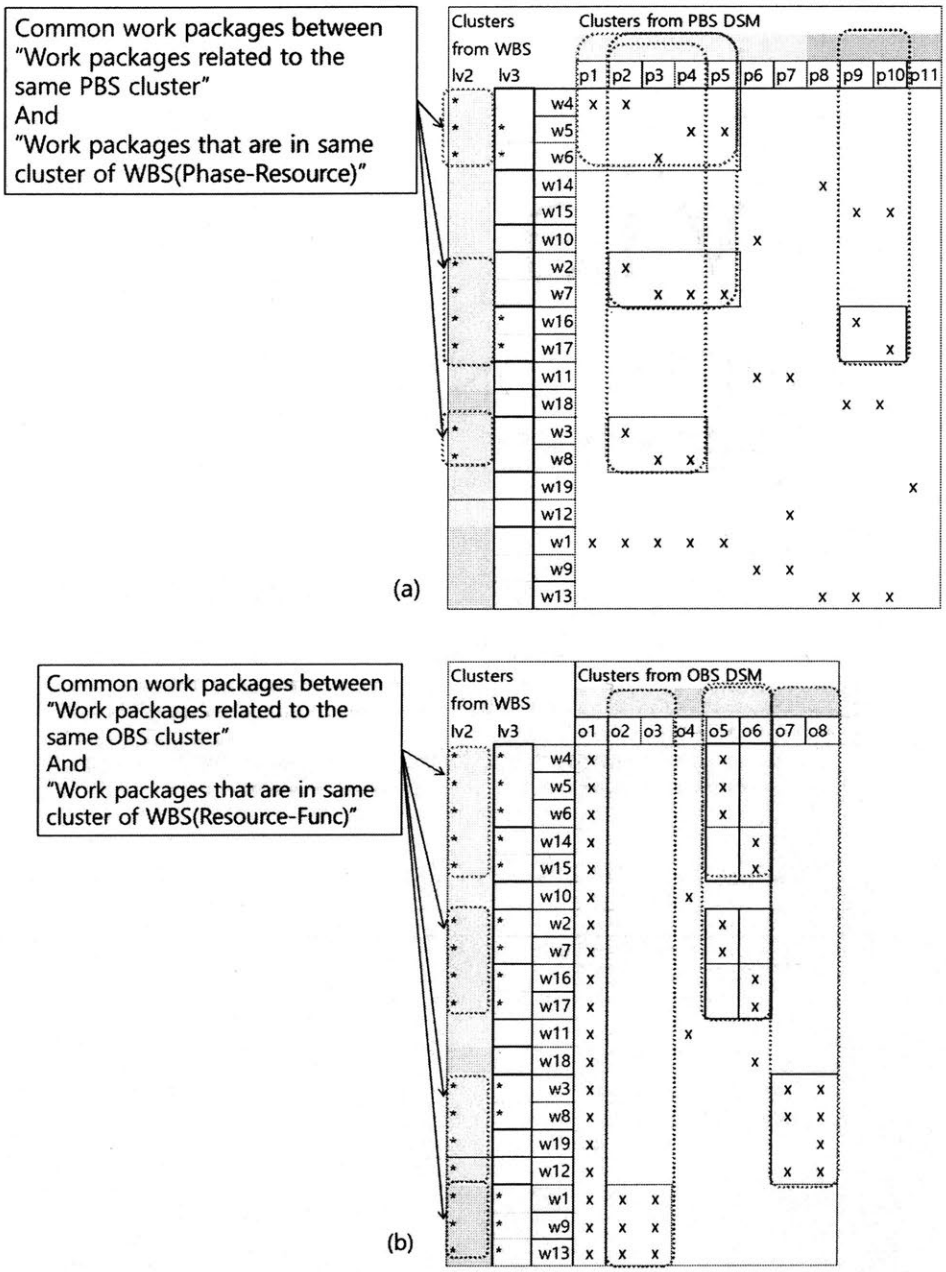


Figure 15. (a) DMM of the WBS(Phase-Resource) and the PBS, (b) DMM of the WBS and the OBS

Table 5. Degree of Alignment between the WBS (Phase-Resource) and the PBS/OBS

Cluster Level	Alignment%(WBS&PBS)	Alignment%(WBS&OBS)
Level2(Phase)	31.6%	84.2%
Level3(Resource)	21.1%	73.7%

Likewise, for each set of level 2 and level 3 breakdown rule, the degree of alignment between the WBSs and the PBS, OBS can be obtained. These degrees of alignment can be converted into the scale of 1 to 10, 1 meaning 1~10%, 2: 11~20%, 3: 21~30%, 4: 31~40%, 5: 41~50%, 6: 51~60%, 7: 61~70%, 8: 71~80%, 9: 81~90%, 10: 91~100% and will be used for the architectural decision option scoring. For more experimental data, level of breakdown was extended from two to three, and the result of the architectural decision option scoring is as table 6. Here, higher number means if that option is chosen then the WBS will be more aligned to the PBS or OBS.

Table 6. Architectural Decision Option Scoring for the Work Breakdown Design Pattern Generator

Architectural Decision	Options	Requirement Scale	
		Product Structure Alignment	Org. Structure Alignment
Lv2 B.R.	Functional.	10	6
	Phase	4	8
	Resource	5	10
	Activity	6	8
Lv3 B.R.	Functional.	10	6
	Phase	4	8
	Resource	5	10
	Activity	6	8
Lv4 B.R.	Functional.	10	6
	Phase	3	8
	Resource	4	10
	Activity	6	8

Using the result of architectural decision option scoring, 64 WBSs with the combination of breakdown rule for each level were generated. Setting the total degree of alignment as the multiple of the alignment values at each level, the total degree of alignment for each WBS is gained as table 7.

Table 7. Total Degree of Alignment for each WBS

No	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Organization Structure Alignment	Product Structure Alignment	No	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Organization Structure Alignment	Product Structure Alignment
1	Func	Func	Func.	216	1000	33	Resource	Func	Func.	360	500
2	Func	Func	Phase	288	400	34	Resource	Func	Phase	480	200
3	Func	Func	Resource	360	500	35	Resource	Func	Resource	600	250
4	Func	Func	Activity	288	600	36	Resource	Func	Activity	480	300
5	Func	Phase	Func.	288	400	37	Resource	Phase	Func.	480	200
6	Func	Phase	Phase	384	160	38	Resource	Phase	Phase	640	80
7	Func	Phase	Resource	480	200	39	Resource	Phase	Resource	800	100
8	Func	Phase	Activity	384	240	40	Resource	Phase	Activity	640	120
9	Func	Resource	Func.	360	500	41	Resource	Resource	Func.	600	250
10	Func	Resource	Phase	480	200	42	Resource	Resource	Phase	800	100
11	Func	Resource	Resource	600	250	43	Resource	Resource	Resource	1000	125
12	Func	Resource	Activity	480	300	44	Resource	Resource	Activity	800	150
13	Func	Activity	Func.	288	600	45	Resource	Activity	Func.	480	300
14	Func	Activity	Phase	384	240	46	Resource	Activity	Phase	640	120
15	Func	Activity	Resource	480	300	47	Resource	Activity	Resource	800	150
16	Func	Activity	Activity	384	360	48	Resource	Activity	Activity	640	180
17	Phase	Func	Func.	288	400	49	Activity	Func	Func.	288	600
18	Phase	Func	Phase	384	160	50	Activity	Func	Phase	384	240
19	Phase	Func	Resource	480	200	51	Activity	Func	Resource	480	300
20	Phase	Func	Activity	384	240	52	Activity	Func	Activity	384	360
21	Phase	Phase	Func.	384	160	53	Activity	Phase	Func.	384	240
22	Phase	Phase	Phase	512	64	54	Activity	Phase	Phase	512	96
23	Phase	Phase	Resource	640	80	55	Activity	Phase	Resource	640	120
24	Phase	Phase	Activity	512	96	56	Activity	Phase	Activity	512	144
25	Phase	Resource	Func.	480	200	57	Activity	Resource	Func.	480	300
26	Phase	Resource	Phase	640	80	58	Activity	Resource	Phase	640	120
27	Phase	Resource	Resource	800	100	59	Activity	Resource	Resource	800	150
28	Phase	Resource	Activity	640	120	60	Activity	Resource	Activity	640	180
29	Phase	Activity	Func.	384	240	61	Activity	Activity	Func.	384	360
30	Phase	Activity	Phase	512	96	62	Activity	Activity	Phase	512	144
31	Phase	Activity	Resource	640	120	63	Activity	Activity	Resource	640	180
32	Phase	Activity	Activity	512	144	64	Activity	Activity	Activity	512	216

6.4. Tradespace Exploration

By setting the organization related performance value as the total alignment value of each WBS and OBS and product related performance value as the total alignment value of each WBS and PBS, the two performance values from table 7 can be presented in a tradespace of "Product Structure Alignment" and "Organization Structure Alignment" (figure 16). Each dot shows the

WBS that was created by using different breakdown rules and its degree of alignment with PBS, and with OBS. (for example, #4: WBS No.4 on the table 7, R: resource breakdown rule, F: functional breakdown rule, A: activity breakdown rule, P: phase breakdown rule)

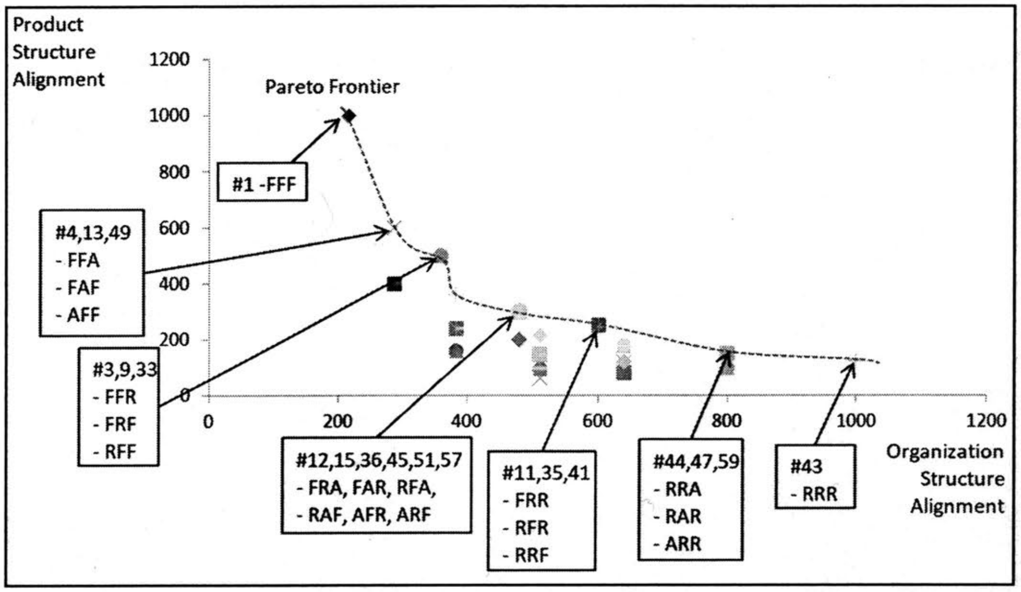


Figure 16. Tradespace of the WBSs by the Work Breakdown Design Pattern Generator

In order to maximize the performance of the project, choosing the WBSs that has its alignment well balanced between the OBS and PBS is preferred. Figure 16 shows that WBSs made of different breakdown rules have different impact in the aspect of organizational and product performance. The dotted red line shows the Pareto frontier which means any WBS on the line dominates other WBSs. Obviously WBS #43, which has maximum alignment with OBS, is created by using resource breakdown rule in all levels. Vice versa WBS #1 consists of functional breakdown rule in all levels. From the left, WBS #4,13,49 are the combination of two functional and one activity breakdown rules. This shows that as activity breakdown rule is used instead of functional breakdown rule product related performance drops, however organization related performance in increased. WBS #3,9,33 are the combination of one resource and two functional, WBS #12,15,36,45,51,57 are the combination of resource, functional, and activity, WBS #11,35,41 are the combination of two resource and one functional, WBS #44,47,59 are the combination of one activity and two resource breakdown. These results depict the change of breakdown rule combination as it moves from WBS highly aligned with PBS toward WBS highly aligned with OBS. WBSs tend to align more with PBS when functional and activity breakdown rules are used. WBSs tend to align more with OBS when resource and activity breakdown rules are used. With the Work Breakdown Design Pattern Generator, project manager can extract few WBS that maximizes its balance with organizational and product performance. And among the WBSs on the Pareto frontier, one can be selected that is most appropriate for the project situation.

7. Validation Analysis with Baseline Scenario

For more detailed illustration with an example, baseline scenario is analyzed. Project requirements and situational factors will be analyzed and will be used as evaluation criteria. Suppose the project requirements and the situations are;

• requires cost efficiency
• requires strong and clear responsibility
• requires clear product scope
• requires schedule efficiency
• requires component dependency consideration
• organization structure is functional type
• project is developed and runs within same district

Through requirement and situation analysis, breakdown rules and requirement will be selected. Since the project is going to be developed and run within same district, the consideration of external circumstances that could harm the project can be neglected. Same architectural decisions and options will be used. For the architectural decision, three levels of breakdown rules, and for each breakdown rule, four options; functional, phase, resource, activity will be selected. The morphological matrix will be as table 8.

Table 8. Morphological Matrix for Architectural Decision and Options of Base Scenario

Architectural Decision	Option1	Option2	Option3	Option4
Level 2 Breakdown Rule	Functional	Phase	Resource	Activity
Level 3 Breakdown Rule	Functional	Phase	Resource	Activity
Level 4 Breakdown Rule	Functional	Phase	Resource	Activity

Requirements can be organized into categories. Cost efficiency and schedule efficiency corresponds to organizational structure; this will be referred to the utility for cost & schedule. Responsibility, product scope, and component dependency corresponds to product structure; this will be referred to the utility for product benefit. Each requirement is weighted appropriately as table 9 and scaled as table 10.

Table 9. Requirements and Metric for Baseline Scenario

Requirement	Weight(%)	Metric
Cost	60	Utility to Cost & Schedule
Schedule	40	
Clear Responsibility	40	Utility to Product Benefit
Clear Product Scope	40	
Component Dependency Consideration	20	

Table 10. Evaluation Scale of the Requirements for Baseline Scenario

No	Requirement	Management Level			
		No effect	Low	Med	High
1	Cost	0	1	2	3
2	Schedule	0	1	2	3
3	Clear Responsibility	0	1	2	3
4	Clear Product Scope	0	1	2	3
5	Component Dependency Consideration	0	1	2	3

According to Norman and Brotherton (2008) functional breakdown helps facilitate communication of responsibility to the stakeholder organizations involved in the project. Deliverable-oriented breakdown is independent of the project organization or execution methodology and considers the component dependency. Task or activity basis refers to things that project team members do toward the goals of the project, such as excavating, pouring, forming, polishing, programming, or testing. Sequential basis reflects the order in which activities are performed. The sequence is often dictated by administrative constraints and is somewhat arbitrary. Use of these two bases is akin to importing the project schedule into the WBS (Rad, 1999). Resource breakdown includes administrative unit, budget account etc. Rad also refer that the administrative unit basis is an infusion of the OBS elements into the WBS and indicates the administrative or organizational division lines. The budget account basis is an infusion of the RBS into the WBS and follows the organization's financial structure. Based on the literature, architecture decisions, requirement metrics, and evaluation scale, the architectural decision option scoring table can be obtained as table 11.

Table 11. Architectural Decision Option Scoring Result for Baseline Scenario

Architectural Decision	Options	Requirement Evaluation Scale				
		1	2	3	4	5
Lv2 B.R.	Functional	2	2	3	3	3
	Phase	3	1	1	2	2
	Resource	1	1	3	1	1
	Activity	1	1	2	2	2
Lv3 B.R.	Functional	2	2	3	3	3
	Phase	3	1	1	2	2
	Resource	1	1	3	1	1
	Activity	1	1	2	2	2
Lv4 B.R.	Functional	2	2	3	3	3
	Phase	3	1	1	2	2
	Resource	1	1	3	1	1
	Activity	1	1	2	2	2

With above scores, two metrics Cost & Schedule and Product Benefit will be measured and used as the two axis of the tradespace.

• Cost & Schedule = 0.6*(value 1 of Lv2 B.R.)*(value 1 of Lv3 B.R.)*(value 1 of Lv4 B.R.)

+ 0.4*(value 2 of Lv2 B.R.)*(value 2 of Lv3 B.R.)*(value 2 of Lv4 B.R.)

• Product Benefit = 0.4*(value 3 of Lv2 B.R.)*(value 3 of Lv3 B.R.)*(value 3 of Lv4 B.R.)

+ 0.4*(value 4 of Lv2 B.R.)*(value 4 of Lv3 B.R.)*(value 4 of Lv4 B.R.)

+ 0.2*(value 5 of Lv2 B.R.)*(value 5 of Lv3 B.R.)*(value 5 of Lv4 B.R.)

Total 64 combinations of architectural decision options and their requirement score can be obtained (table 12).

Table 12. Cost & Schedule and Product Benefit Values for Baseline Scenario

No	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Cost & Schedule	Product Benefit	No	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Cost & Schedule	Product Benefit
1	Func	Func	Func.	8	27	33	Resource	Func	Func.	4	16.2
2	Func	Func	Phase	8.8	14.4	34	Resource	Func	Phase	4.4	7.2
3	Func	Func	Resource	4	16.2	35	Resource	Func	Resource	2	12.6
4	Func	Func	Activity	4	18	36	Resource	Func	Activity	2	10.8
5	Func	Phase	Func.	8.8	14.4	37	Resource	Phase	Func.	4.4	7.2
6	Func	Phase	Phase	11.6	8.4	38	Resource	Phase	Phase	5.8	3.6
7	Func	Phase	Resource	4.4	7.2	39	Resource	Phase	Resource	2.2	4.8
8	Func	Phase	Activity	4.4	9.6	40	Resource	Phase	Activity	2.2	4.8
9	Func	Resource	Func.	4	16.2	41	Resource	Resource	Func.	2	12.6
10	Func	Resource	Phase	4.4	7.2	42	Resource	Resource	Phase	2.2	4.8
11	Func	Resource	Resource	2	12.6	43	Resource	Resource	Resource	1	11.4
12	Func	Resource	Activity	2	10.8	44	Resource	Resource	Activity	1	8.4
13	Func	Activity	Func.	4	18	45	Resource	Activity	Func.	2	10.8
14	Func	Activity	Phase	4.4	9.6	46	Resource	Activity	Phase	2.2	4.8
15	Func	Activity	Resource	2	10.8	47	Resource	Activity	Resource	1	8.4
16	Func	Activity	Activity	2	12	48	Resource	Activity	Activity	1	7.2
17	Phase	Func	Func.	8.8	14.4	49	Activity	Func	Func.	4	18
18	Phase	Func	Phase	11.6	8.4	50	Activity	Func	Phase	4.4	9.6
19	Phase	Func	Resource	4.4	7.2	51	Activity	Func	Resource	2	10.8
20	Phase	Func	Activity	4.4	9.6	52	Activity	Func	Activity	2	12
21	Phase	Phase	Func.	11.6	8.4	53	Activity	Phase	Func.	4.4	9.6
22	Phase	Phase	Phase	16.6	5.2	54	Activity	Phase	Phase	5.8	5.6
23	Phase	Phase	Resource	5.8	3.6	55	Activity	Phase	Resource	2.2	4.8
24	Phase	Phase	Activity	5.8	5.6	56	Activity	Phase	Activity	2.2	6.4
25	Phase	Resource	Func.	4.4	7.2	57	Activity	Resource	Func.	2	10.8
26	Phase	Resource	Phase	5.8	3.6	58	Activity	Resource	Phase	2.2	4.8
27	Phase	Resource	Resource	2.2	4.8	59	Activity	Resource	Resource	1	8.4
28	Phase	Resource	Activity	2.2	4.8	60	Activity	Resource	Activity	1	7.2
29	Phase	Activity	Func.	4.4	9.6	61	Activity	Activity	Func.	2	12
30	Phase	Activity	Phase	5.8	5.6	62	Activity	Activity	Phase	2.2	6.4
31	Phase	Activity	Resource	2.2	4.8	63	Activity	Activity	Resource	1	7.2
32	Phase	Activity	Activity	2.2	6.4	64	Activity	Activity	Activity	1	8

These values can be plotted on the tradespace as figure 17.

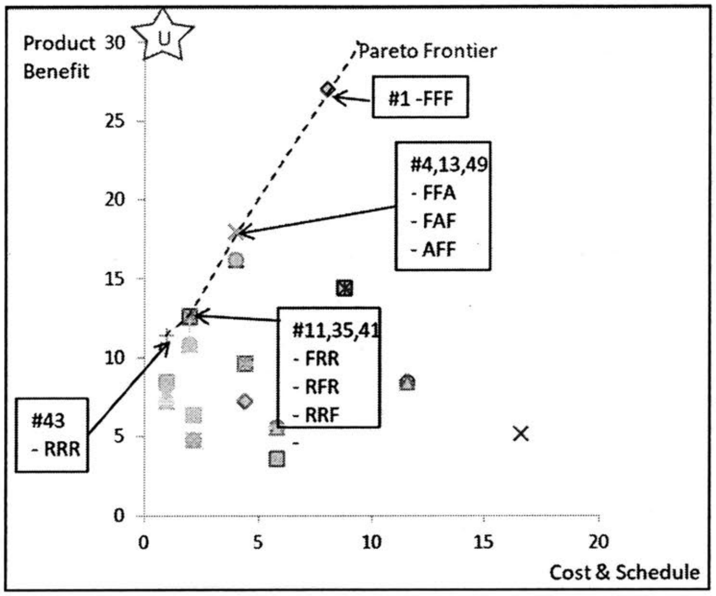


Figure 17. Tradespace of WBSs created by the Work Breakdown Design Pattern Generator for Baseline Scenario

In the tradespace, the utopia point is on the left top corner where cost & schedule is minimized and product benefit is maximized. And WBSs that minimizes the cost & schedule while maximizes product benefit stands along the dotted red Pareto Frontier. WBS #1 has the highest product benefit. This is quite obvious since it uses functional breakdown as all level 2~4 breakdown rules (;func-func-func). WBS #4, 13, and 49 uses func-func-activity, func-activity-func, and activity-func-func respectively. As activity breakdown rule plays a role, the product benefit drops because it has lower impact on requirements related to the product benefit than the functional breakdown, however it helps to reduce the schedule and cost. WBS #11(;func-resource-resource), #35(;resource-func-resource), #41(;resource-resource-func) consists of two resource breakdown rule and one functional breakdown rule. As resource breakdown rule increases, the cost & schedule is decreased and also product benefit decreased. Among the WBSs on the Pareto frontier, project manager should use other project situation to choose the most appropriate WBS. If the nature of the project requires high product benefit and can afford cost & schedule up to scale 5, WBS #4, 13 or 49 would be an appropriate WBS for the project.

Based on the above analysis, the results are compared with the WBS-PBS/OBS alignment. Figure 17 tells us the WBSs on the Pareto frontier are WBS #1, WBS #4/13/49 (; combination of func, func, and activity), WBS #11/35/41 (; combination of resource, resource, and func), and WBS #43. Figure 16 shows the WBSs on the Pareto frontier that maximizes the balance between WBS and PBS, and between WBS and OBS. Among the WBSs, WBS #4/13/49 and WBS #11/35/41 are plotted on the Pareto frontier as figure 18. This shows that the WBS which is highly aligned with PBS or OBS brings good product related performance and organization related performance respectively.

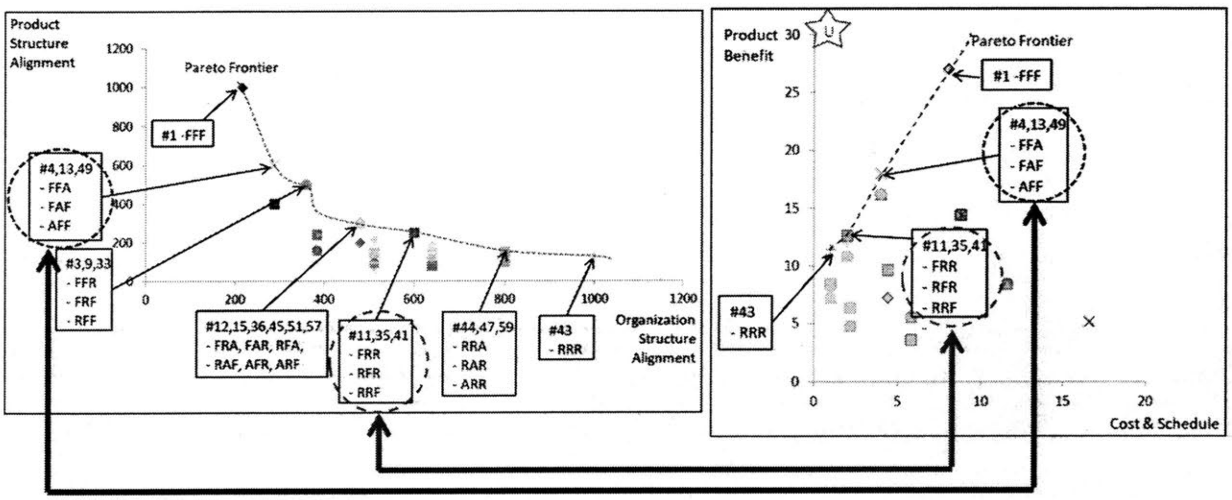


Figure 18. Comparison between the two Tradespace

8. Scenario Analysis

In order to test the robustness of the Work Breakdown Design Pattern Generator and to observe the outcomes for different circumstances, scenario analysis is performed for two different scenarios. In the Work Breakdown Design Pattern Generator, different scenario can be designed by changing the requirements, breakdown rule, and the situations of the project. If the project has a nature that is highly dependent to the geographical difference, location breakdown or area breakdown rule can be used. If the project is purely target based, the product benefit would mean different and calculated differently. First scenario has a high geographical influence and second scenario focuses on product quality.

8.1. Scenario Geo

In the first scenario, "scenario Geo", the nature of the project is mostly focused on the communication and team works. The technology being used is not highly complicated, just clear responsibility is required. However the project will run in two different areas where legal, procurement circumstances are different. Below are the summarized requirements.

- requires lot of communication with stakeholders
- requires good teamwork performance
- requires medium technology
- requires clear responsibility
- requires clear scope
- organization structure is project type
- project will run in two different areas

In scenario Geo, the project will run in two different areas. This means that external circumstances will have high impact on the project. Architectural decisions will be level 2 breakdown rule, level 3 breakdown rule, level 4 breakdown rule and for the options, functional, geological, resource, activity breakdown rules will be selected. The morphological matrix will be as table 13.

Table 13. Morphological Matrix for Architectural Decision and Options of Scenario Geo

Architectural Decision	Option1	Option2	Option3	Option4
Level 2 Breakdown Rule	Functional	Geological	Resource	Activity
Level 3 Breakdown Rule	Functional	Geological	Resource	Activity
Level 4 Breakdown Rule	Functional	Geological	Resource	Activity

Requirements can be organized into categories. Requirements of frequent communication with the stakeholder and good teamwork performance are highly related to the organizational structure. Product scope and external circumstances due to locational difference are corresponding to product structure. Again the requirements will be represented by the Utility of Cost & Schedule and the Utility of Product Benefit. Each requirement is weighted appropriately as table 14 and scaled as table 15.

Table 14. Requirements and Metric for Scenario Geo

Requirement	Weight(%)	Metric
High communication rate	50	Utility to Cost & Schedule
High teamwork	50	
Clear responsibility	30	Utility to Product Benefit
Clear product scope	20	
Geographical circumstance consideration	50	

Table 15. Evaluation Scale of the Requirements for Scenario Geo

No	Requirement	Management Level			
		No effect	Low	Med	High
1	High communication rate	0	1	2	3
2	High teamwork	0	1	2	3
3	Clear responsibility	0	1	2	3
4	Clear product scope	0	1	2	3
5	Geographical circumstance consideration	0	1	2	3

Functional breakdown helps facilitate communication of responsibility to the stakeholder organizations involved in the project (Norman and Brotherton, 2008). Geographical breakdown is a kind of deliverable-oriented breakdown but is more focused on the locational difference. This breakdown will help to clarify the external circumstance that needs to be considered with clear responsibility. Resource breakdown enables to track each resource group as they proceed with the project. Using resource breakdown makes it is easier to expedite certain tasks or projects without relying on others, and therefore can reduce the schedule before the set deadline. The scoring of the options at each architectural decision to the requirements is as table 16.

Table 16. Architectural Decision Option Scoring Result for Scenario Geo

Architectural Decision	Options	Requirement Scale				
		1	2	3	4	5
Lv2 B.R.	Functional	3	1	3	3	1
	Geographical	1	1	3	2	3
	Resource	2	2	3	1	3
	Activity	1	1	2	2	1
Lv3 B.R.	Functional	3	1	3	3	1
	Geographical	1	1	3	2	3
	Resource	2	2	3	1	3
	Activity	1	1	2	2	1

Lv4 B.R.	Functional	3	1	3	3	1
	Geographical	1	1	3	2	3
	Resource	2	2	3	1	3
	Activity	1	1	2	2	1

With above scores, two metrics Cost & Schedule and Product Benefit will be measured and used as the two axis of the tradespace.

- Cost & Schedule = 0.5*(adjusted value 1 of Lv2 B.R.)*(adjusted value 1 of Lv3 B.R.)*(adjusted value 1 of Lv4 B.R.) + 0.5*(adjusted value 2 of Lv2 B.R.)*(adjusted value 2 of Lv3 B.R.)*(adjusted value 2 of Lv4 B.R.)

- Product Benefit = 0.3*(value 3 of Lv2 B.R.)*(value 3 of Lv3 B.R.)*(value 3 of Lv4 B.R.)
  + 0.2*(value 4 of Lv2 B.R.)*(value 4 of Lv3 B.R.)*(value 4 of Lv4 B.R.)
  + 0.5*(value 5 of Lv2 B.R.)*(value 5 of Lv3 B.R.)*(value 5 of Lv4 B.R.)

Total 64 combinations of architectural decision options and their requirement score can be obtained (table 17). And their values are plotted on the tradespace as figure 19.

Table 17. Cost & Schedule and Product Benefit Values for Scenario Geo

No.	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Cost & Schedule	Product Benefit	No.	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Cost & Schedule	Product Benefit
1	Func	Func	Func.	17.5	14	33	Resource	Func	Func.	11	7.3
2	Func	Func	Geo.	17.5	10.5	34	Resource	Func	Geo.	11	7.2
3	Func	Func	Resource	13	7.3	35	Resource	Func	Resource	8	5.9
4	Func	Func	Activity	19.5	9.5	36	Resource	Func	Activity	12	5.2
5	Func	Geo.	Func.	17.5	10.5	37	Resource	Geo.	Func.	11	7.2
6	Func	Geo.	Geo.	17.5	10.5	38	Resource	Geo.	Geo.	11	11.8
7	Func	Geo.	Resource	13	7.2	39	Resource	Geo.	Resource	8	8.6
8	Func	Geo.	Activity	19.5	7.5	40	Resource	Geo.	Activity	12	5.8
9	Func	Resource	Func.	13	7.3	41	Resource	Resource	Func.	8	5.9
10	Func	Resource	Geo.	13	7.2	42	Resource	Resource	Geo.	8	8.6
11	Func	Resource	Resource	10	5.9	43	Resource	Resource	Resource	6	7.1
12	Func	Resource	Activity	15	5.2	44	Resource	Resource	Activity	9	4.6
13	Func	Activity	Func.	19.5	9.5	45	Resource	Activity	Func.	12	5.2
14	Func	Activity	Geo.	19.5	7.5	46	Resource	Activity	Geo.	12	5.8
15	Func	Activity	Resource	15	5.2	47	Resource	Activity	Resource	9	4.6
16	Func	Activity	Activity	22.5	6.5	48	Resource	Activity	Activity	13.5	3.8
17	Geo.	Func	Func.	17.5	10.5	49	Activity	Func	Func.	19.5	9.5
18	Geo.	Func	Geo.	17.5	10.5	50	Activity	Func	Geo.	19.5	7.5
19	Geo.	Func	Resource	13	7.2	51	Activity	Func	Resource	15	5.2
20	Geo.	Func	Activity	19.5	7.5	52	Activity	Func	Activity	22.5	6.5
21	Geo.	Geo.	Func.	17.5	10.5	53	Activity	Geo.	Func.	19.5	7.5
22	Geo.	Geo.	Geo.	17.5	17.5	54	Activity	Geo.	Geo.	19.5	8.5
23	Geo.	Geo.	Resource	13	11.8	55	Activity	Geo.	Resource	15	5.8
24	Geo.	Geo.	Activity	19.5	8.5	56	Activity	Geo.	Activity	22.5	5.5
25	Geo.	Resource	Func.	13	7.2	57	Activity	Resource	Func.	15	5.2
26	Geo.	Resource	Geo.	13	11.8	58	Activity	Resource	Geo.	15	5.8
27	Geo.	Resource	Resource	10	8.6	59	Activity	Resource	Resource	12	4.6
28	Geo.	Resource	Activity	15	5.8	60	Activity	Resource	Activity	18	3.8
29	Geo.	Activity	Func.	19.5	7.5	61	Activity	Activity	Func.	22.5	6.5
30	Geo.	Activity	Geo.	19.5	8.5	62	Activity	Activity	Geo.	22.5	5.5
31	Geo.	Activity	Resource	15	5.8	63	Activity	Activity	Resource	18	3.8
32	Geo.	Activity	Activity	22.5	5.5	64	Activity	Activity	Activity	27	4.5

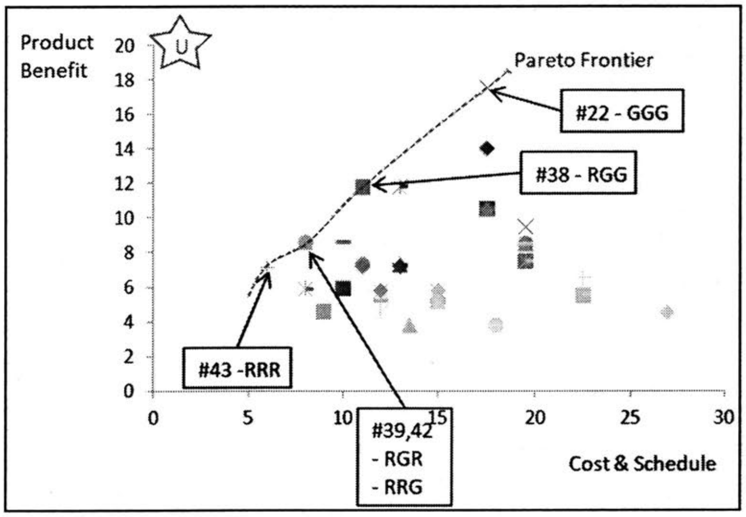


Figure 19. Tradespace of WBSs created by the Work Breakdown Design Pattern Generator for Scenario Geo

Figure 19 shows five WBSs are along the Pareto frontier. The one which maximizes the product benefit, however requires high cost and schedule is WBS #22 which consists of geological breakdown for all three levels (;Geo-Geo-Geo). This is because the project highly affected by the geologically different circumstances and the geological breakdown rule considers this nature the most. WBS #38 is using Resource-Geo-Geo breakdown rules. As one resource breakdown rule is applied instead of geological, it shows the cost & schedule decrease with the product benefit. Interesting point is the performance of WBS #38 (11,11.8) is higher than WBS #23 (13,11.8) and #26 (13,11.8), which are using Geo-Geo-Resource and Geo-Resource-Geo respectively. It shows that WBS #38 has lower cost and schedule however has same product benefit compared to WBS #23 and #26. This again shows that even if the types of breakdown rules used are same, different order of the breakdown rule affects the project performance differently. WBS #39 and #42 are also on the Pareto frontier, which are using Resource-Geo-Resource and Resource-Resource-Geo respectively. As the resource breakdown rule increases cost and schedule reduces but also product benefit. But compared to the difference between WBS #22 and #38, the difference between WBS #38 and #39, WBS #42 is much smaller. The difference is originated from the difference between geological breakdown rule's impacts on the requirements and resource breakdown rule's impact on the requirements. Lastly WBS that minimizes the cost & schedule however also has minimum product benefit is WBS #43 which is using resource breakdown structure for all three levels. Since the organizational structure here is project based structure, which has simple contact point and good flexibility, and since the product complexity is not that high, close alignment with the organizational structure would bring better performance. WBS #38 would be an appropriate WBS for this scenario.

8.2. Scenario Product

In the second scenario, "scenario Product", the project has the highest priority for the product quality and innovation. The product is very complex and has high dependencies between the components. However communications with the stakeholder and decision arrangement does not seem to be that complicated in this case. Below are the summarized requirements.

- requires high component dependency consideration
- requires clear scope
- requires low communication with stakeholder
- requires schedule control
- organization structure is project type
- project will run within same district

Architectural decisions will be level 2 breakdown rule, level 3 breakdown rule, level 4 breakdown rule and for the options, functional, phase, resource, activity breakdown rules will be selected. The morphological matrix will be as table 18.

Table 18. Morphological Matrix for Architectural Decision and Options of Scenario Product

Architectural Decision	Option1	Option2	Option3	Option4
Level 2 Breakdown Rule	Functional	Phase	Resource	Activity
Level 3 Breakdown Rule	Functional	Phase	Resource	Activity

Level 4 Breakdown Rule	Functional	Phase	Resource	Activity

Requirements can be organized into categories. Component dependency consideration, clear product scope, and clear responsibility are related to the product structure. Efficient schedule control and communication rate are related to organization structure. Again the requirements will be represented by the Utility of Cost & Schedule and the Utility of Product Benefit. Each requirement is weighted appropriately as table 19 and scaled as table 20.

Table 19. Requirements and Metric for Scenario Product

Requirement	Weight(%)	Metric
Component dependency consideration	70	Utility to Product Benefit
Clear product scope	20	
Clear responsibility	10	
Efficient schedule control	80	Utility to Cost & Schedule
Communication rate	20	

Table 20. Evaluation Scale of the Requirements for Scenario Product

No	Requirement	Management Level			
		No effect	Low	Med	High
1	Component dependency consideration	0	1	2	3
2	Clear product scope	0	1	2	3
3	Clear responsibility	0	1	2	3
4	Efficient schedule control	0	1	2	3
5	Communication rate	0	1	2	3

Deliverable-oriented breakdown rule decomposes in terms of the components (physical or functional) that make up the deliverable (Taylor, 2003). Breaking down by components reveals the connection of each component and help one to understand the dependency better. Time-phased breakdown rule is the one that is used on very long projects. It breaks the project into major phases instead of tasks. This can clarify the scope by dividing works in phases and also gives advantage to the schedule control. The scoring of the options at each architectural decision to the requirements is as table 21.

Table 21. Architectural Decision Option Scoring Result for Scenario Product

Architectural Decision	Options	Requirement Scale				
		1	2	3	4	5
Lv2 B.R.	Functional	3	3	2	1	2
	Phase	2	3	1	3	1
	Resource	1	1	2	3	3
	Activity	1	2	3	2	1
Lv3 B.R.	Functional	3	3	2	1	2
	Phase	2	3	1	3	1
	Resource	1	1	2	3	3
	Activity	1	2	3	2	1
Lv4 B.R.	Functional	3	3	2	1	2
	Phase	2	3	1	3	1
	Resource	1	1	2	3	3
	Activity	1	2	3	2	1

With above scores, two metrics Cost & Schedule and Product Benefit, will be measured and used as the two axis of the tradespace.

- Cost & Schedule = 0.8*(adjusted value 4 of Lv2 B.R.)*(adjusted value 4 of Lv3 B.R.)*(adjusted value 4 of Lv4 B.R.) + 0.2*(adjusted value 5 of Lv2 B.R.)*(adjusted value 5 of Lv3 B.R.)*(adjusted value 5 of Lv4 B.R.)

- Product Benefit = 0.7*(value 1 of Lv2 B.R.)*(value 1 of Lv3 B.R.)*(value 1 of Lv4 B.R.)
  + 0.2*(value 2 of Lv2 B.R.)*(value 2 of Lv3 B.R.)*(value 2 of Lv4 B.R.)
  + 0.1*(value 3 of Lv2 B.R.)*(value 3 of Lv3 B.R.)*(value 3 of Lv4 B.R.)

Total 64 combinations of architectural decision options and their requirement score can be obtained (Table 22).

Table 22. Cost & Schedule and Product Benefit Values for Scenario Product

No.	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Cost & Schedule	Product Benefit	No.	Lv2 B.R. Option	Lv3 B.R. Option	Lv4 B.R. Option	Cost & Schedule	Product Benefit
1	Func	Func	Func.	23.2	25.1	33	Resource	Func	Func.	8	8.9
2	Func	Func	Phase	9.6	18.4	34	Resource	Func	Phase	3.6	6.4
3	Func	Func	Resource	8	8.9	35	Resource	Func	Resource	2.8	3.5
4	Func	Func	Activity	16.8	11.1	36	Resource	Func	Activity	6	4.5
5	Func	Phase	Func.	9.6	18.4	37	Resource	Phase	Func.	3.6	6.4
6	Func	Phase	Phase	6	14	38	Resource	Phase	Phase	2.6	4.8
7	Func	Phase	Resource	3.6	6.4	39	Resource	Phase	Resource	1.4	2.4
8	Func	Phase	Activity	8.4	8.4	40	Resource	Phase	Activity	3.4	3.2
9	Func	Resource	Func.	8	8.9	41	Resource	Resource	Func.	2.8	3.5
10	Func	Resource	Phase	3.6	6.4	42	Resource	Resource	Phase	1.4	2.4
11	Func	Resource	Resource	2.8	3.5	43	Resource	Resource	Resource	1	1.7
12	Func	Resource	Activity	6	4.5	44	Resource	Resource	Activity	2.2	2.3
13	Func	Activity	Func.	16.8	11.1	45	Resource	Activity	Func.	6	4.5
14	Func	Activity	Phase	8.4	8.4	46	Resource	Activity	Phase	3.4	3.2
15	Func	Activity	Resource	6	4.5	47	Resource	Activity	Resource	2.2	2.3
16	Func	Activity	Activity	13.2	6.3	48	Resource	Activity	Activity	5	3.3
17	Phase	Func	Func.	9.6	18.4	49	Activity	Func	Func.	16.8	11.1
18	Phase	Func	Phase	6	14	50	Activity	Func	Phase	8.4	8.4
19	Phase	Func	Resource	3.6	6.4	51	Activity	Func	Resource	6	4.5
20	Phase	Func	Activity	8.4	8.4	52	Activity	Func	Activity	13.2	6.3
21	Phase	Phase	Func.	6	14	53	Activity	Phase	Func.	8.4	8.4
22	Phase	Phase	Phase	6.2	11.1	54	Activity	Phase	Phase	7	6.7
23	Phase	Phase	Resource	2.6	4.8	55	Activity	Phase	Resource	3.4	3.2
24	Phase	Phase	Activity	7	6.7	56	Activity	Phase	Activity	8.6	4.7
25	Phase	Resource	Func.	3.6	6.4	57	Activity	Resource	Func.	6	4.5
26	Phase	Resource	Phase	2.6	4.8	58	Activity	Resource	Phase	3.4	3.2
27	Phase	Resource	Resource	1.4	2.4	59	Activity	Resource	Resource	2.2	2.3
28	Phase	Resource	Activity	3.4	3.2	60	Activity	Resource	Activity	5	3.3
29	Phase	Activity	Func.	8.4	8.4	61	Activity	Activity	Func.	13.2	6.3
30	Phase	Activity	Phase	7	6.7	62	Activity	Activity	Phase	8.6	4.7
31	Phase	Activity	Resource	3.4	3.2	63	Activity	Activity	Resource	5	3.3
32	Phase	Activity	Activity	8.6	4.7	64	Activity	Activity	Activity	11.8	5

These values can be plotted on the tradespace as figure 20.

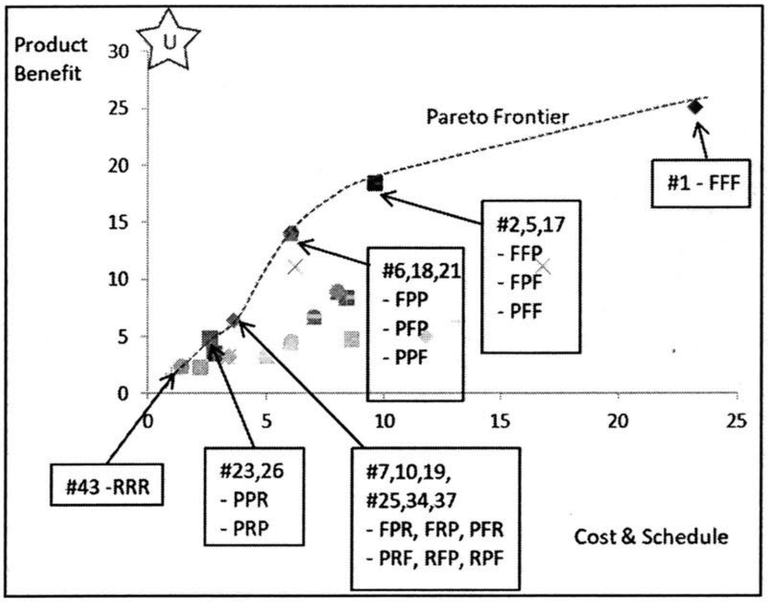
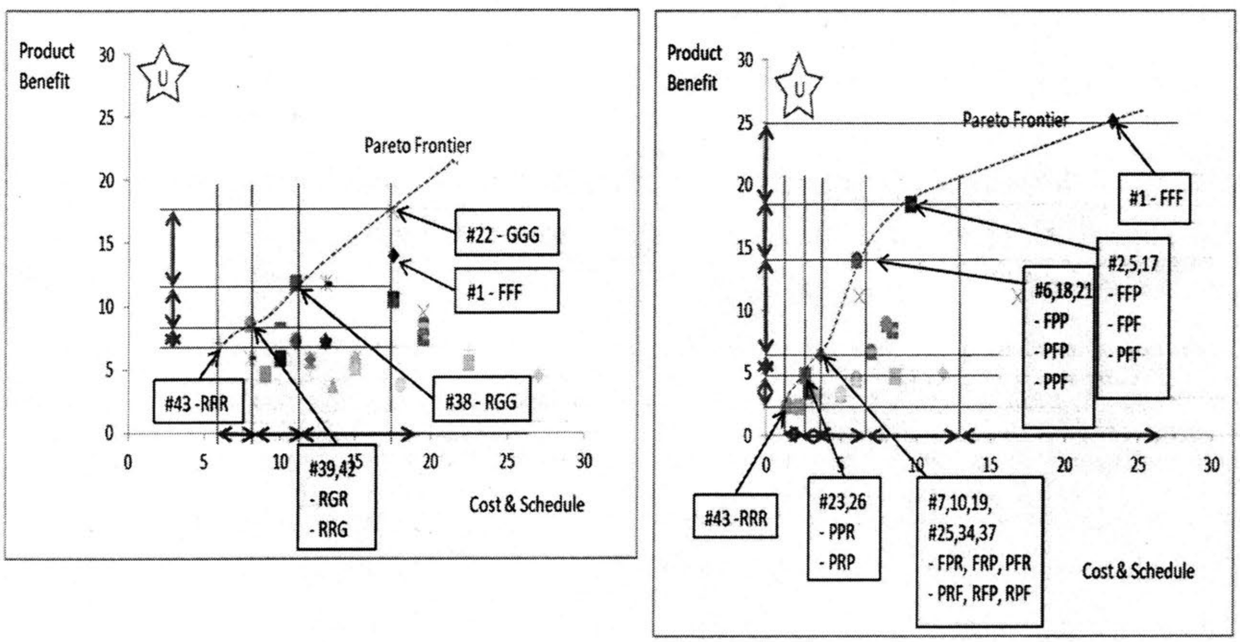


Figure 20. Tradespace of WBSs created by the Work Breakdown Design Pattern Generator for Scenario Product

Figure 20 shows the highest product benefit is made by WBS #1, using functional breakdown rule in all levels. Second highest product benefit belongs to WBS #2, 5, and 17 where using two functional breakdown rule and one phase breakdown rule. This is because phase breakdown rule not only clarifies scope but also helps schedule control. The next high product benefit comes from WBS #6, 18, and 21 which consists of two phase breakdown rule and one functional breakdown rule. It tells that as the breakdown rules shifts from functional to phase, the product benefit decreases along with the cost & schedule. As WBSs move toward low cost & schedule and low product benefit along the Pareto frontier, the breakdown rules change into combination of func-phase-resource and eventually resource-resource-resource. However it shows that the product gap between the combination of breakdown rule with resource and without resource is much greater that the cost & schedule gap. This is due to the nature of project that requires low communication with stakeholders. As it is depicted on the tradespace, projects that is highly related to the product nature and is less related to organizational nature tends to have better performance when WBS is more aligned with PBS.

8.3. Comparing the Two Scenarios

This section compares the tradspace exploration of the two scenarios analyzed in the previous sections. Tradespaces for the two scenarios are shown as figure 21. They both show that as the WBSs use more resource breakdown rules to decompose the work, cost and schedule efficiency enhances; however, the product benefits decline. Functional breakdown tend to contribute to the product benefit. Although geographical breakdown rule shows higher product benefit in scenario Geo, functional breakdown still has high product benefit. This could be interpreted as an example of a particular breakdown rule that suits the unique nature of the project.



(a) Tradespace of Scenario Geo **(b) Tradespace of Scenario Product**

Figure 21. Tradespace Comparison of Two Scenarios

In the context of product benefit, both tradespaces show that the gap between the WBSs tends to become smaller as the purity of breakdown rules becomes lower. For example, in figure 21(a), the gap between the WBS #39 and #38 is smaller than the gap between the WBS #38 and #22. Likewise in figure 21(b), similar change in gaps is shown. On the other hand, in the context of cost & schedule, the gap increases as the purity of the breakdown rules become lower.

9. Conclusion

This chapter provides insights and findings from the chapter six, seven, and eight. These insights are then related to the principles of system thinking, returning to the motivation of the thesis. This chapter concludes with the limitations of this thesis and the future works.

9.1. Insights and Findings

Analysis of a baseline scenario and two other scenarios shows that the combinations of different breakdown rules can lead to different performances of the project.

- Functional breakdown rule tends show high product benefits when requirements and situation of the project focus more on the product structure. In such case, a high alignment exists between the WBS made of functional breakdown rule and a PBS.
- Resource breakdown and activity breakdown rules are more related to the organizational structure, managing cost and schedule of the project. For projects that emphasize the organization-related requirements, such as communication and schedule efficiency, a WBS more aligned with the organizational structure tends to perform better.
- Geographical breakdown rule plays an important role in cases when circumstances differ due to locational differences. In this case, the preferred WBSs may not be on the Pareto frontier of the alignment tradespace.

Tradespace results show how a balanced set of WBSs perform better than other, unbalanced, WBSs. However, there are times where the WBSs below the Pareto frontier lead to high performance, such as scenario Geo. Situations where the organizational structure is very flexible (project structure), the alignment between the WBS and OBS had little impact. Depending on the nature of the project and situation, a particular breakdown rule that maximizes the project performance was found. All in all, the Work Breakdown Design Pattern Generator demonstrates how to use different breakdown rules to create different WBSs, to show different project performance, and to show the alignment with product and organizational structure.

Going back to the principle of system thinking, the principle of balance tells us the importance of maintaining an appropriate balance between the conflicting tradeoffs. The change in alignment between a WBS and PBS/OBS depending on the combination of different breakdown rules and the different performances depicted by each WBS show how the Work Breakdown Design Pattern Generator follow the principle of balance. The principle of decomposition says that decomposition affects how performance is measured, and how the organization should be set up. Various kinds of WBSs generated from the Work Breakdown Design Pattern Generator, and their different performances shown in the tradespace explain how this method follows the principle. Returning to the system thinking principle of robustness of architectures, sometimes architectures off the Pareto frontier are more robust. Using the fuzzy Pareto frontier instead of the Pareto frontier in the context of architectural optimization can also help identify the more robust architectures. In situations where the impact of the geological difference is high, optimized WBSs are located slightly off the Pareto frontier.

The motivation for this thesis was to find a way to improve the performance of PPP project. The original question from the beginning was, "Is there a way to build an efficient WBS that would lead to high performance or success in PPP project?" Related literature review made the initial ideas about the causal relationship between a good WBS and high performance more concrete. Literature review regarding WBS and DSM led to a new approach in creating a WBS, which is to design a WBS based on the ability to compare the alternatives and their benefits. Other research about OBS, PBS, and DMM helped to improve this new approach by adding the notion of the relationship between an alignment of structures and the performance. With a guide from the system thinking principles, the Work Breakdown Design Pattern Generator allows us to create and show WBSs of different combinations of breakdown rules and their performances comparatively. To answer the original question through the whole journey of this paper, it is possible to enhance the performance of PPP projects in the early phase by creating an efficient WBS. The method presented and the examples shown in this paper demonstrate a way that structural alternatives can be generated so that the various partners in dialogue can shape their work approach efficiency in the early phase.

9.2. Limitations

In this paper, the organizational structure and product structure were assumed to be given. This made the situation and calculations simple. The reality however, is much more complicated. This same method can also be used in situations where there are changes in organizational and product situations. In some cases, small changes to the product structure or changes to the organizational structure could allow for more Pareto options. These further considerations would improve the overall alignment between the WBS and PBS or the WBS and OBS.

Also we assumed there was no loop process for WBS refinement, which means the processes of returning back to WBS for refinement during the project development are not considered. However, in actual project development, this loop process occurs frequently. For example a new dependency can be discovered in the middle of the project and have a high impact on the WBS. Chances are that the impact of an element might turn out differently from the original assumption. Further analysis considering this loop impact would make the Work Breakdown Design Pattern Generator more concrete.

9.3. Future work

Research has noted that despite the advantage of PPP many project fail due to the risk and resource sharing, multiple parties involved, and the large size and complexity of the project. The underlying methodology of the Work Breakdown Design Pattern Generator studied in this thesis would guide an efficient way to plan a project in the early phase to maximize its performance. However this is only the beginning of innovation. At this stage, further study and tests to refine the Work Breakdown Design Pattern Generator are needed. The work presented in this thesis may be thought of as an empirical endeavor to conceive and design an efficient WBS. In order to apply the Work Breakdown Design Pattern Generator in more general situations, the following work streams are recommended for a future work.

Breakdown rules in each cluster on the same level shall be differentiated. In this study, the same breakdown rules were applied on the same level. The effect of different breakdown rules on different levels was looked into. However as the clusters decompose into smaller chunks, each chunk may have a different nature and characteristics. The performance related to the requirements can be improved when separate breakdown rules are applied for each chunk.

Also, the level of decomposition should be expanded. For simple comparison and calculations, only 3 levels of decomposition was considered. However, PPP projects are mostly large, complex projects and consist of many levels of decomposition. If more levels are considered, bigger differences between the combinations of breakdown rules are expected. And maybe if the number of the levels is more than certain amount, the performance of the Work Breakdown Design Pattern Generator might change.

Finally the chain effects of the high-level breakdown rule to the low-level breakdown rule need to be more considered. If the decomposition level increases, the effect of a particular breakdown rule on a particular level may differ from another level. Since the decisions on high-levels have bigger impacts than in low-levels, it is assumed that as levels go deeper, the effect of a particular breakdown rule will be small. However that difference may bring different results in the tradespace.

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