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Flexibility in Port Planning and Design

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Recently, flexibility has received much attention from port researchers, designers, and managers. This is because the stability of the competitive environment of the past has been replaced by increasing uncertainty. The current economic crisis and the recent trends in ports and shipping sectors are causing port planners to rethink their approach towards port planning, design, and project evaluation. Attributes such as flexibility and adaptability can provide a port infrastructure system with the capacity to be useful under changing requirements, making it robust in face of uncertainty, lengthening its economic lifetime, and thereby guaranteeing payback on investments.
Due to the burgeoning research in the field, new measures, new evaluation methods, and new theories and approaches for incorporating flexibility in large-scale infrastructure design have appeared. Adaptive port planning methods are being advocated in place of traditional planning approaches. 'Design for obsolescence' is being suggested as an alternative for 'building in redundancy' in port infrastructure design. 'Flexibility' and 'adaptability' are being added to the list of life cycle properties. Real option methods are being advocated for project evaluation under uncertainty.
The objective of this paper is to examine the present trends in the port sector and the current practices in port planning, design, and project evaluation. Having identified the inadequacy of these practices under uncertainty, the paper recommends integrating flexibility in designs and processes. It further suggests that Adaptive Port Planning methods, which include Real Options Analysis for valuing flexibility, are better suited in times of uncertainty than the traditional methods.

Keywords: port planning, adaptive planning, uncertainty, flexibility, port trends.

1. Introduction

The stability of the competitive business environment of the past decades has been replaced by increasing uncertainty. The major drivers of this uncertainty, namely, the ongoing globalization and liberalization, and rapid leaps in technology (especially in information and communication technology) are influencing all infrastructure sectors (Lempert, 2003; de Neufville and Scholtes, 2006; van Wee and Flyvbjerg, 2010). Recent developments related to the ports and shipping

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sectors, such as containerization, and trends in logistics and transport, are placing increasing demands on ports (Alderton, 1999; Meersman *et al*., 2008; Notteboom and Rodrigue, 2008). Congestion in existing ports and their hinterlands, insufficient water depth, changing requirements, and increased economic activity, call for adaptation of existing ports, or alternatively, investments in new infrastructure. The development, expansion, and modernization of ports, as well as the roads, rail, and inland waterway systems, which have often suffered from years of under-investment or total neglect, are the major challenges facing many ports today. Port planners, designers, and managers (and decisionmakers) must face up to these challenges.

Added to the volatile external environment is the fact that ports have a long lifetime, the investments are irreversible and lumpy (World Bank and IBRD, 2007), and the system is highly dynamic, characterized by emergent behavior with many possible feedback loops and uncertain outcomes (Bekebrede and Mayer, 2006). Projects suffer from delays and budget overruns, since the costs of mitigating measures to avoid negative effects of unexpected developments during the project lifetime are not included in project evaluation. The result is often a poorly developed port system, which becomes inadequate and subsequently obsolete. Some examples of ports or terminals made obsolete, due to lack of uncertainty considerations, can be found in (Taneja *et al*., 2010a).

This paper examines whether the current practices in port planning, design, and evaluation are adequate for present uncertain times and, if found inadequate, proposes suitable solutions. The objective of this research is to provide port planners, designers, and decisionmakers, who are confronted with many strategic uncertainties and risks during the project lifetime, with ways and means of dealing with present and future uncertainty.

Research methodology

The approach used for this study was to first carry out a general literature review of the challenges facing large scale infrastructures, and thereafter an extensive literature review to establish the current trends (economic, technological, and institutional) in the ports and shipping sectors. The objective was to gain insight into the major driving force(s) behind these trends. In order to examine the current practices in port planning, design, and evaluation, interviews and desk research at the Port of Rotterdam Authority, engineering firms, and design consultants was carried out. Existing Master Plans, traditional port infrastructure designs, and decisionmaking procedures for project investment decisions were examined. A literature review was carried out to support the assumption that flexibility is indeed the best approach for dealing with uncertainty. The expansion of the theme of flexibility in the context of port infrastructures is a result of the application of ideas and research from other infrastructure domains.

Background

The basic functions of a port are: performing services in response to societal demand, and providing infrastructure, operating procedures, management practices, and development policies to accommodate and facilitate these services. Further, a *port development project* refers to the entire port lifecycle, i.e., feasibility study, preliminary design, detailed design, implementation, and exploitation (including maintenance and adaptation). An element of port planning and design is necessary for any port development. A *Master Plan* of a port includes a layout of the port wherein land is allocated to the various uses required, describes the phases needed to implement the plan, and gives an indicative implementation scheme per development phase. It incorporates preliminary designs of the major elements of port infrastructure, which are worked out later in a detailed design phase. The term '*planning*' in this paper refers to Master Planning, and '*design*' refers to the detailed design phase. A Master Plan simultaneously reflects the strategic objectives of government, port authority, and other stakeholders, the requirements of port users and operators, and the needs of local communities (which are in turn determined by a myriad of global forces). *Project evaluation* refers to the process of assessing, in a structured way, the viability of a project, and often involves comparing alternatives through use of financial or other criteria. Port planning and design are irrevocably related to port operations and management.

Outline of the paper

The paper is structured as follows: Section 2 examines the changing trends in the port sector and Section 3 examines the current practices in planning and design in order to identify the gaps in the traditional methods of port planning, design, and evaluation. Section 4 suggests that attributes such as flexibility can provide a port infrastructure system with the capacity to adapt to changing requirements, making it robust in face of uncertainty. An Adaptive Port Planning approach is recommended in Section 5. This approach provides guidelines for incorporating flexibility in port projects, and includes methods of project evaluation that value flexibility. Some general conclusions follow in Section 6.

2. Examining current trends in the ports sector

This section examines the current trends in the port sector, many of which are common to other large scale infrastructures. These changing trends are a reflection of the uncertain environment.

2.1. Current trends

Evolution in functions of a port

Ports have moved from performing nautical, cargo handling, stacking, and distribution functions to being multimodal nodes in the logistic chain[4](Heaver *et al.,* 2001; Olivier and Slack, 2006; Meersman *et al.,* 2008). At a modern port, transport flows from one mode to another, all transport flows come together and then disperse. Therefore, port planning needs to focus on the seamless handling of the flows, and efficient and economic transport. As Notteboom and Rodrigue (2008) state, the expectations about the future growth of containerized traffic will have to be matched by a physical reality of transport infrastructures. The provision of capacity alone is not sufficient, and future developments for container terminals and their infrastructure will be focused more on throughput than capacity. Little attention was previously given to the landside function of the port, whereas now systematic planning from the point of view of the 'through' transport function is vital. Ports are also being segmented into large 'load centers' and smaller 'feeder' and niche ports. In addition, supply chain management has brought new demands to port performance. More stakeholder requirements than we have known so far need to be satisfied. This has brought about changes in the strategic planning of ports and the design of port infrastructure.

Increasing volatility

The port sector has always been volatile, and new demands have always been placed on ports. An example is the Port of Rotterdam (PoR). The extent of new harbor area and the water-depth has continued to increase over the years, while the period of time between the successive

[4] A description of three generations of ports, distinguished on the basis of the criteria such as port development policy, strategy and attitude, the scope and extension of port activities, and the integration of port activities and organization, can be found in UNCTAD (2005).

expansion projects (e.g., Rotterdam city terminals, Botlek in the late 1940's, Europoort starting in 1958, Maasvlakte in the late 1960's, Maasvlakte 2 in 2008) is becoming shorter. Whereas the Leuvehaven area sufficed for more than 200 years and the Waalhaven for 40 years, the much larger Botlek area was too small after only two years, and Europoort was almost full before construction was complete. Surprises can happen in the other direction as well. The planned activities for Maasvlakte (ship building and steel factories) had moved to Asia before the reclamation project was finished.

So, ever growing volatility in the port sector, stimulated by the global trends of liberalization, economic expansion of Europe, and changes in producer and consumer markets (China, India, Brazil, Eastern Europe), is adding to the uncertainty surrounding port planning, design, and investment.

Space and capacity constraints

From a maritime shipper's perspective, using large containerships is a logical step, since it utilizes economies of scale, thus lowering costs per TEU carried. However, from a port perspective, this results in intense pressures in terms of infrastructure investments, such as maritime access routes and terminals (Notteboom and Rodrigue, 2008). The increase in ship sizes (requiring deeper drafts and longer berths) and the rapid increase in the operational scale and scope leading to increasing space requirements has been responsible for ports close to city centers (e.g., Antwerp, Rotterdam, Los Angeles) to shift operations further away. Even the inefficient and shallow public ports in many countries (e.g., Nigeria, India) are trying to expand on a small scale. Limited space for expansion is creating the need for intensive use of available land, innovative solutions such as spatial bundling, underground infrastructure, and transport corridors.

Focus on detailed forecasts

Forecasts are fundamental to port planning and design. Most ports attach a lot of importance to detailed cargo forecasts based on analysis by commodity of historic trends, international, national and local developments, and their competitive position. Sometimes forecasts can be meaningless. For instance, in the words of the Port of London Authority (Tobin, 1975): 'We knew that containerization would get a fast place but we thought that the reorientation of conventional general cargo would take long and we seriously doubted the capacity of the system to compete on very long trade routes. Our planners and economists applied a scientific method as basis of their analyses and forecasts. As we can establish afterwards, they were invariably wrong. They underestimated the developments. Their comparisons were lacking an essential factor, namely the strength of a brilliant concept.' The increasing recognition of uncertainty in forecasts is pushing planners to seek other means and ways, such as building flexibility into their projects.

Policies and decisionmaking

Even more difficult than trying to forecast technology and innovation is forecasting policies and laws. A port development project is large-scale, complex, and has a long lead time. A great deal of research is required before development can get underway – for instance, into the feasibility and consequences of the planned changes pertaining to all related disciplines and stakeholders. (In the Netherlands, the parties are required to go through all the steps of a complex and lengthy Key Physical Planning procedure, which involves an extensive Environment Impact Assessment). The increasing regulations and stricter policies result in the time between conceiving an infrastructure project and its implementation becoming increasingly longer. Meanwhile, because circumstances change, the planning needs to start all over again.

Regulation may occur in the form of new physical requirements, performance requirements, sustainability requirements, or economic changes that impact costs. Government intervention may also provide opportunities for installation of an innovative technology in the future that may not have existed at the time of initial design. Future regulation is an uncertainty applicable to planning, design, and investment decisions made today.

From hard to soft management

Port projects are seen as engineering projects requiring a hard systems approach that dictates a single perception of problems, objectives, methods, criteria, and solutions. The performance measures are generally time, cost, and quality. However, as ports seek to strike a balance between social, ecological, and business needs and objectives, it is being realized that 'soft' issues are equally important. This is because a network of multiple heterogeneous stakeholder groups with divergent perceptions, values, and interests are involved, and soft issues such as community perception, safety, environmental impacts, legal acceptability, and political and social impacts, need to be addressed at the beginning of the project. Change management and stakeholder management (Dooms *et al.*, 2004) are becoming well known in ports. The role of economists, environmentalists, lawyers, and managers is gaining more importance than that of engineers, who are challenged with having to design around numerous constraints.

From a 'building in redundancy' to a 'design for obsolescence' approach

A frequently discussed issue is whether a better approach would be to design an inexpensive infrastructure with a shorter design lifetime in order to match the economic lifetime, which is becoming shorter. And the issue of safety is brought up often: engineers require the infrastructure to have the same factor of safety at the beginning of its lifetime as at the end. Since this lifetime is as much as 50-100 years in the case of civil structures, upholding the same safety factor requires continuous and expensive maintenance. These issues influence port planning and design.

Tailor-made port solutions

The port industry, by nature, is very conservative, and departures from the norm have often proven to be difficult. This is, for instance, in contrast with the offshore industry, where design and operation of gas and oil platforms have continually been adapted to new requirements. There is also less opportunity today for port construction that does not satisfy established or agreed customer demand. Most countries base their expansion plans on detailed traffic forecasts and a detailed analysis of engineering options, in order to ensure financial viability. (China proved an exception when it took the decision to develop new deep water container ports on a large scale in a short time — e.g., Dalian, Tianjin, Qingdao, Shanghai, Ningbo, Xiamen, and Shenzhen — thus laying the foundations for China's container hubs). This leaves less scope for speculative building and innovation. A tailor-made and optimized design for a single user or cargo, based on a fixed specification, has limited flexibility and adaptability for the future. This approach may be seen as a defensive approach, driven by a cost-benefit analysis and only sanctioned by a letter of intent of the investor, or better still, a signed contract.

Role of Master Plans

The financial and economic viability of large scale infrastructures is getting more attention due to cost overruns and delays in recent large infrastructure projects (Flyvbjerg *et al.*, 2003). Due to the long payback period and irreversible nature of investments, a project's feasibility and acceptability for its commercial development is under heavy scrutiny. Between the 1960's and 1980's, port Master Plans served as land-use plans, centrally controlled, and largely linked with governmental growth strategies and financing, whereas nowadays a Master Plan serves as a basis for a business case (e.g., the Maasvlakte 2 project in the PoR). This requires different insights on the part of port planners and designers.

Impacts of technology

Modern technology is being implemented within the maritime industry, and the shape and texture of the traditional container terminal is changing in response. These technologies are being used to address a whole variety of issues, including operational efficiencies, environmental conditions, and security (Johansen, 2007). The impacts have focused on several areas: bigger vessels, new equipment configurations, new logistic concepts, new cargo handling concepts, advancements in ICT leading to development of information systems such as GIS (Geographic Information Systems), dynamic real time control of operations, efficient data collection and processing time, new camera systems, new gate processing systems, and the introduction of radiation detection monitoring systems. All of these changes are leading to increased terminal productivity (and efficiency), but they are also placing new demands on port infrastructures.

Developments in construction technology

Developments in construction materials and technology, and increasing globalization allowing access to experience towards worldwide best practice, have an impact on port planning. However, these practices are not always relevant for developing countries, where local solutions should find favor. For developed countries, the advantages of the new developments are sometimes offset by an increasing focus on sustainability and reusability.

Port administration models

Today, the landlord port is the dominant port model in larger and medium sized ports, although this has not always been true. The infrastructure provided by the landlord port is leased to private operating companies or to industries, while a single entity (the private sector) owns and operates the cargo handling equipment, in addition to providing and maintaining its own superstructure. Port planning is often initiated by existing clients and their immediate needs. This port model has an impact on port planning, since it can result in overcapacity due to pressure from various private operators, as well as misjudging the proper timing of capacity additions (World Bank and IBRD, 2007).

Increasing role of private sector

The private sector is financing the construction of entire terminals, including quay walls, land reclamation, dredging, superstructure, and equipment. This has given rise to a large variety of financing contract forms, such as Design and Build (DB), Design, Build and Operate (DBO), Design, Build and Maintain (DBM) and, if financial risks are included, Design, Build, Finance and Maintain (DBFM) and Build, Operate and Transfer (BOT). Ports that were previously in a government setup have no guarantees of a captive cargo and have to carry out active marketing. The increasing role of private enterprise in the port sector is having a direct influence on port management, operations, financing, and consequently on port planning.

New contract forms and stress on budget and schedule

Once a project is awarded based on one of the contract forms (listed above), the speed of implementation is of essence to achieve a realistic capital cost profile, so extreme pressure is put on the designer to confirm his conceptual designs via data collection, small scale model testing, and computer simulations, leading to frozen project specifications that can be used for actual tendering of engineering procurement and construction contracts (Huisman, 1999). The time available for pre-engineering (concept and specification development), as well as the implementation times are reduced. This reduced front-end time creates challenges for design engineers, specialized consultants, and project managers.

Clustering

Industrial clusters are geographic concentrations of private companies that may compete with one another or complement each other as customers and suppliers in specialized areas of production and distribution. Clustering of related activities improves the competitive advantage of cluster participants by increasing their productivity, reducing transaction costs among them, driving technological innovation, and stimulating the formation of new business spin-offs. Several notable port-centered industrial clusters have developed over the last 50 years, and there is increasing pressure to seek synergy with related activities. This has given rise to the trend of large ports, such as the Port of Rotterdam, preferring to primarily attract clusters, and placing the other clients around clusters.

Environmental and safety concerns

An emerging trend concerns the increasing attention for protection of the environment and safety. Ports have to deal with these issues that were in the past not considered to be within their scope. Global media coverage brings these issues to the door of the public and is capable of stirring strong emotions and strongly influencing the public perception. This situation argues for more consistent attention being given to environmental issues beginning in the design phase, and ending with ex-post assessments of actual, as compared to predicted, environmental impacts (Flyvbjerg, *et al.* 2003). Non-compliance can result in costly delays and may result in the project becoming infeasible.

Life cycle perspective

Most old port infrastructures were vast and solid and not always adaptable to the rapidly changing pattern of shipping and cargo. The seemingly unlimited budgets after the Second World War reinforced the trend of pre-investing in some extra robustness in structure to allow for future increases in loads. However, margins have diminished in a much more competitive environment. Nowadays, from a capital investment, operating, and maintenance point of view, the approach to infrastructure design is changing. The structures are designed keeping in mind future maintenance activities. Pre-investment for the future is a point of many hefty debates. Pre-fabricated, assembled modules are preferred in order to reduce implementation times. Structure designs take into account the local construction practices rather than relying on large equipment mobilized by international contractors. Life cycle costs are scrutinized critically, and each step of capital expenditure is balanced against expected revenues (Huisman, 1999).

Standardization and modularity, both in designs and processes, in order to reduce costs and increase flexibility, are being opted for. A life cycle perspective on projects, which ensures that likely future changes are taken into consideration during planning, and the resulting infrastructure is better equipped to deal with future changes, is increasingly being recommended. This perspective can reduce financial risks and achieve significant cost savings.

Focus on customer orientation/ satisfaction

The new motto, also applicable in the port sector, seems to be 'Supply the customers with what they want, to standards and specification they want, and at a price that suits their needs.' Shipping companies, especially in the container sector, demand increasingly higher levels of service (for the same price), and the port sector is oriented towards efficiency and high service levels.

2.2. Driving force behind major trends

From an analysis of the trends discussed in Section 2.1, it can be concluded that the driving force behind the most significant trends for the three areas under discussion (port planning, design, and project appraisal) is an uncertain environment.

3. Current practices in port planning, design, and project evaluation

3.1. Introduction

The previous section dealt with major trends in the port sector, and concluded that the major driving force behind these trends was uncertainty. The resulting question is whether current approaches to port planning, design, and evaluation can cope with this uncertainty.

The literature mentions the following limitations in current practices: static nature of planning, lack of integrated systematic planning, insufficient understanding of time and costs related to a thorough planning, no coordination with regional and national planning, lack of insight and experience of local authorities and their advisors, disregard for local factors, too much focus on infrastructure facilities and not enough on operational and maintenance aspects, too much focus on sea side and not enough on landside, rigidity in extrapolation of historical developments, ignoring uncertainties while planning, and confusing risk and uncertainty with each other (Pigna, 2008).

The literature cites the following major reasons for the failure of large infrastructural projects: changes in scope / aim of project, weak project definition, interfering government, weak contracts, management problems, conflicting perspectives from different actors, optimistic cost and risk estimates, timing of tender, large and risky contracts, and variable components in those contracts, an imbalance between process and project, and the project organization (Verbraeck, 2009). It is important to understand how organizations currently plan and deal with these ventures. In this section some port Master Plans, and standard practices in planning, design, and project appraisal are examined, to see how they do or do not handle uncertainty and flexibility.

3.2. Master Planning

Some features of the examined Master Plans are discussed here.

The Israel Strategic Port Development Plan 2055 (IPC, 2005) deals with the ports of Ashdod and Haifa, Israel's two major ports on the Mediterranean coast. It examines the long-term demand for port facilities and the options available for meeting those demands. Future demand, future vessel size, long-term space requirements for port expansion, and future operational requirements have been identified as the major uncertainties for the port Master Plan. Though the 50-year forecast has been used as the basis of the planning, it is rightly observed that economic forecasts covering such a long time period are likely to carry a significant margin of error and the figures should be treated with caution.

Flexibility has been defined as the ability of the plan to cope with variations and to allow adjustments to the lay-out of the plan. The following strategies have been suggested in order to cope with the uncertainties: spacious marine layout; terminal areas with sufficient depth and length; long quays to improve the flexibility for operations and vessel berthing, as well as flexibility with regard to allocating terminal concessions, the possibility to extend quays and terminals when necessary without serious constraints created by the need for disproportionately expensive construction, and infrastructure designed in such way that it can cope with technical changes of the superstructure, equipment, etc.

The plan recommends that quantification of the effects of the various uncertainties be carried out through constructing scenarios, estimating the likelihood of each scenario, and determining the investment required for later adaptations. Flexibility is one of the criteria in the multi-criteria analysis for evaluating various development options. Phasing development has also been proposed, and the advantages of postponing large investments and saving capital cost have been included in project evaluation.

Flexibility has been a major goal in the Master Planning of the Maasvlakte 2 (Rotterdam Mainport Development Project, 2008). The motto of the Master Plan is *Create your own future* – that is, the client should be given the maximum flexibility in the planning of his terminal on Maasvlakte 2. Having acknowledged that the only manner to deal with future uncertainty is to make flexible and robust designs that are adequate for different futures, a Master Plan cycle has been set up whereby every year the Master Plan is adapted to the newest insights. The Master Plan gets more detailed in every cycle as more information comes available. The design and construction contract with the building consortium gives it an enormous amount of freedom in how it carries out the project, as long as it satisfies the schedule of requirements. Moreover, flexibility in time is achieved by adapting the development of Maasvlakte 2 to the actual market demand, and phasing the implementation of plans. The following phase will be developed in due time, when newer information will provide a better insight into the future (another motto: *Client in sight, land in view*). The terminals (meant for containers at present) are of modular size and can be readily adapted for other cargo. The marine infrastructure is planned for future vessels, keeping in mind future flexibility.

The Gangavaram port located on the east coast of India has the deepest draft of all the ports in India, and is one of the few greenfield ports. The port Master Plan was prepared in 2005 following the methodology followed by most modern ports, which included forecasting traffic considering the likely economic growth for three growth scenarios (pessimistic, moderate, and optimistic) and a detailed Master Plan was prepared for the optimistic scenario. The most flexible alternative 'multipurpose port handling all cargoes' was selected out of five options. The harbor and the port layouts were planned for short, medium, and long term developments (2006, 2012, and 2020), but the plans were prepared to accommodate further facilities to handle any additional cargo traffic beyond what is forecast for 2020. Adequate water area, waterfront, and back up area is reserved for expansion in the layout.

The Marine Terminals Master Plan 2020 of the port of Portland (Port of Portland Authority, 2000) explicitly states that a comprehensive approach was used to prepare and refine a series of facility alternatives through an interactive process involving all stakeholders in order to arrive at a road map for investment decisions by the Port. It is a flexible plan with sustainable balance for the Port. Thus, the increasing importance of stakeholder participation and flexibility in port development projects is duly acknowledged.

These examples illustrate that uncertainty considerations are playing an increasing role in Master Planning. On the other hand, the forecasts on which traditional port planning is based are invariably inaccurate over a longer time horizon (this subject is dealt with in detail by Flyvbjerg *et al*. (2003)). The process of forecasting, which forms the basis of Master Planning, is mostly managed by specialized professionals. Economists and statisticians develop models to predict future trade and supply them to designers, planners, and engineers. In short, there is a great professional distance between the producers of the forecasts and those using these figures for planning and design. Physical and institutional distance between these groups further reinforces this separation (de Neufville and Scholtes, 2009). Though we have moved from point forecasts to scenario development and analysis, only a few scenarios (generally base case, optimistic, and pessimistic) are considered for planning and investment decisions for time horizons varying from 5-50 years. Over a long time horizon, this approach basically amounts to ignoring uncertainty.

3.3. Engineering Design

Infrastructure design is generally carried out by engineering consultants who receive the functional specifications of the client (port owner or port authority) laid down in a 'terms of reference' document. They focus on translating these functional requirements into technical specifications, and designing the elements of an infrastructure system based on these deterministic figures, using norms and standards (specified in the same document). Engineers often do not recognize that these figures are based on very uncertain forecasts of future demands and services, and will probably result in designs inadequate and unsuitable for the longer term. The practice in engineering of designing to fixed specifications is deeply entrenched in the overall process for developing technological projects (de Neufville, 2004). Uncertain factors in design generally refer to material properties and loads on structures. This is taken into account through (minimum) compliance with the requisite norms and standards, wherein safety factors to be incorporated in designs are prescribed.

Often, alternative design options are investigated for a project, but the traditional, mostly low-cost alternative is generally opted for, which can be attributed to a lack of long-term vision. Flexibility comes with a cost, and without a life cycle perspective and long-term uncertainty considerations (and financial tools that can evaluate this flexibility), the additional cost is difficult to justify. This could explain why examples of flexible port infrastructure are few and far between[5].

In short, designers do not habitually think in terms of uncertainty and flexibility, standard design practice does not deal with the reality of rapid change, and leaves little room for flexibility to cope with exogenous risks. A framework that addresses uncertainty is required.

3.4. Project evaluation

Large infrastructure projects, such as port projects, affect markets throughout the economy, and in case of government funding (from a broad perspective of welfare economics), a cost-benefit analysis[6] for evaluating investment in infrastructure is required. Every effect of an investment project can be systematically estimated and, wherever possible, given a monetary value. The analysis normally uses single best estimates of cost and value, and uses techniques such as discounted cash flow analysis (DCF). Most financial tools explicitly consider only one expected outcome (e.g., expected profit or net present value) and science can provide very little guidance to policymakers beyond offering them simple decision rules to aid them in their analysis of uncertain situations e.g., maximax, minimax regret, and equal probability rule (Thomas and Maurice, 2005). Due to the many uncertainties surrounding the planning, implementation, and

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[5] In the last few years, various modular concepts for quay walls have been proposed, such as Containerland and Maxisteck (CUR, 2005), but not built.

[6] In infrastructure and spatial development projects, economic valuation in the Netherlands is done in accordance with the OEI-guidelines (Overzicht Effecten Infrastructuur)(CPB/NEI, 2001).

operating environment of a project, it is neither feasible, nor desirable, to express the net benefits of a large project in a single monetary value (CPB/NEI, 2000), as is currently the practice.

In many countries, the government is responsible for financing basic infrastructure, and an often occurring problem is that the decision to invest does not necessarily originate at the same level of government as the level having the financing responsibility. Because of this, the interest of public officials to increase the efficiency and profitability of port assets is usually limited, because they are not held accountable for the success or failure of their investment decisions (World Bank and IBRD, 2007).

Project appraisal of port infrastructure is mostly carried out at the feasibility stage (mostly on the basis of a concept Master Plan) by economists, while the technical design is carried out at a later stage, almost always by a third party (engineering consultants or advisors). The increasing popularity of various forms of design and construct contracts is reinforcing this trend. The motivation of the third party is generally limited to finding an adequate and reasonably priced design alternative that meets the specifications, and flexibility is not high on the list of objectives.

The current financial tools do not value flexibility. Besides, the linear decisionmaking process (involving preliminary design of alternatives followed by an initial evaluation, detailed design of the chosen alternative, and final project evaluation) does not leave room for a flexible option identified in the detailed design stage to be included in the initial project evaluation. This can lead to misguided decisionmaking.

3.5. Limitations of current methods

Complex projects inevitably involve a high degree of uncertainty. As shown above, the current approaches to port planning, design, and evaluation do not take uncertainty into account and result in plans and designs for port infrastructures that prove inadequate under changing requirements. Consequently, the infrastructure has a shortened economic lifetime, which makes payback on the investments risky.

Project managers, in order to curb the negative effects of risks, often implement a risk management program. Methods such as Enterprise Risk Management (ERM) have evolved to address the needs of various stakeholders. ERM involves identifying developments relevant to the organization's objectives (risks and opportunities), assessing them in terms of likelihood and magnitude of impact, determining a response strategy, and monitoring progress. Thus, risk is mostly treated as a separate conflicting engineering discipline (Vassalos *et al.* 2006)[7]. A systematic and integrated approach to planning of a (port) project is missing (de Neufville, Scholtes Stefan *et al.*, 2000; Burghouwt, 2007; Kwakkel *et al.,* 2010).

Risk analysis and strategic planning are treated as independent activities, and practiced in different time frames. This leaves no scope for including flexibility in the front-end phase of the project, which, especially for infrastructures, can prove to be most cost-effective. The lack of an integrated approach leads to many parallel initiatives and processes, so that there is an overlap or neglect of responsibilities. When ad-hoc risk reduction measures are applied at a later stage, and lead to extra budget and time, it often comes as a source of surprise.

Due to the lack of uncertainty considerations, the objectives and sub-objectives of a port development are often not clearly defined. There is often no clarity in the short-term and long-

[7] Integral risk analysis and risk management is practiced only by a few of the larger organizations (26% in the Netherlands) (Freriksen, Swagerman et al. 2006). Only 19% of the organizations carry out a risk analysis at the time of a big investment.

term visions (which leads to conflicting performance criteria and demands paradoxical solutions).

The designers do not habitually think in terms of uncertainty and do not realize that flexible designs permit multiple pathways of project evolution, according to the scenarios that develop. The decisionmaking related to engineering (technical aspects) and investments is separated. The linear approach followed for most port development projects means that the decisionmaking cannot benefit from new information that reduces uncertainty.

Advanced techniques for evaluating flexibility in projects and justifying its extra cost do not form a part of standard practice. The traditional methods, such as DCF, assume that decisions are made now (and will not change later), and fix the cash flow streams for the future. Flexibility in infrastructure as well as in decisionmaking can enhance the value of a project, since it enables managers to develop strategies that react to changing circumstances, take advantage of opportunities, and insure the projects against downside risk. The value of this flexibility should be included in the standard evaluation of a project.

The following sections discuss a possible solution to this situation.

4. Flexibility as an approach for dealing with uncertainty

4.1. Introduction

This section begins by discussing current literature that proposes flexibility as a strategy for dealing with the uncertainties surrounding large infrastructure projects. Next, it defines flexibility in the context of port infrastructures. It depicts a port as a layered system, in order to identify where flexibility can be (effectively) incorporated in the system. Four strategies as to the timing of flexibility are discussed, and the major drivers, enablers, and barriers to flexibility are listed. Finally, the general attitude of various stakeholders towards flexibility in infrastructures is discussed.

4.2. A perspective on uncertainty and flexibility in infrastructures

In planning situations there is always a gap between what is known and what should be known. In order to bridge this gap, we need flexibility (Faludi, 1977). Under uncertainty, taking decisions becomes more difficult: the certainty that the payoff will justify the investment decreases, while the importance of acquiring strategic advantage over the competition becomes increasingly important. Investors should aim to benefit from uncertainty rather than reducing uncertainty to manageable levels in standard practices (Porter, 1980; Ahmed *et al.* 1996; Volberda, 1998). Scholtes (2007, p.1) writes: “The most important uncertainty management concept for large projects is that of flexibility. Managers should integrate flexible reaction capacity in the project, so that new schemes can be developed during the course of the project if a wholly unforeseeable event occurs”. Moses (2004, p.6-7) writes: “Though the generally recognized properties of engineering systems are function, performance and cost, a life cycle perspective on the system emphasizes non-traditional properties or goals of systems, often called *ilities*, which include: flexibility, adaptability, scalability, safety, durability, sustainability, reliability, recyclability, maintainability, and quality in order to manage the evolution of systems in an uncertain world. Predicting the uncertain future is difficult, but to the extent one can use past events as a guide to designing flexible alternatives or options into a system, the cost of adapting to similar events in the future will be greatly reduced”.

In the words of de Neufville *et al.* (2007, p.3): “We need a paradigm for planning and design of large-scale engineering systems that deals effectively with the reality that the actual future so regularly differs substantially from the forecast. We need concepts and procedures that enable us to anticipate possible uncertainties, and enable us to deal with them efficiently as they arise. In one word, we need to develop the flexibility to react to events, to take advantage of new opportunities, and to exit from unproductive pathways. We need this because the value that can be expected from a flexible system can be vastly greater than the value derived from a system designed around a specific expected future. Designers of large-scale systems need “real options”, that is, the flexibility to alter development trajectories as needed”.

The next section defines the term flexibility in the context of ports.

4.3. Defining flexibility in the context of ports

Port design is very much dictated by ship design and cargo size and shape. According to Bellis (1990), flexibility in future port design is the ability to accommodate any reasonable shape of vessel and type of cargo and any related movement or storage of that cargo throughout the port area. Two decades ago this definition of flexibility might have been apt, but today it needs to be re-examined. Certain cargo, such as containers, requires a high degree of specialization aimed at optimizing each container move and at a fast turnaround time of ships. Such cargo requires dedicated facilities.

Ports can be seen as complex, large-scale, multidisciplinary infrastructure systems that evolve with varying rates of change, and are confronted with volatile environments. In the 1950’s-1960’s, efficiency was the key word in infrastructure planning, in the 1970’s, quality became the buzz word. And, in the present uncertain times, flexibility has become a necessary complement to efficiency and quality, in order to achieve competitive advantage (Volberda, 2003).

The ready ability of a system to change in response to external forces is referred to as *flexibility* (Nilchiani, 2005). The ability of the system to change in response to developments within the system boundary is referred to as *adaptability*. In the present context, we will use the two terms interchangeably. Thus, flexibility and adaptability represent the ease with which the system can respond to uncertainty in a timely and cost-effective manner, to sustain or increase its value delivery. Based on this definition, a port with the capability to change so as to be functional under new, different, or changing requirements (with minimal extra investment, and without appreciable loss in overall service quality, in terms of efficiency and reliability), can be said to be a flexible port.

4.4. Sources of flexibility in the port system

A port infrastructure system can be described using the three-layer infrastructure model (‘*inframodel*’) depicted in Figure 1 (Thissen and Herder, 2003). The three layers are the physical infrastructure layer, the operational layer, and the services layer. All three layers are subject to external influences. As the following sections illustrate, the challenge is to provide flexibility in the layers so that the layers and the system as a whole can adapt to changing requirements. Some example of the flexible options available to planners, designers, and decisionmakers in the port sector at various levels of the inframodel are listed in Figure 2.

The lowest layer, consisting of the physical-infrastructure, is the most static. Therefore its flexibility needs to be built upfront. Quay walls of modular construction (built of pre-fabricated concrete blocks, concrete caisson units, or steel jackets) can be dismantled and transported to a new location as needed. Modular construction that enables upscaling or downgrading can also provide flexibility in size, capacity, or layout. Similarly, a floating quay wall is mobile and can be towed to any desired location in the port. Multifunctionality is yet another source of flexibility in infrastructures. Some examples of multifunctional infrastructure are: a quay wall for mooring ships also designed to store dry or liquid bulk cargo; a terminal building that can used as a storage facility or as an office; a handling and transport system that can cater to coal as well as mineral ore; and underground pipes for transporting more than one type of liquid.

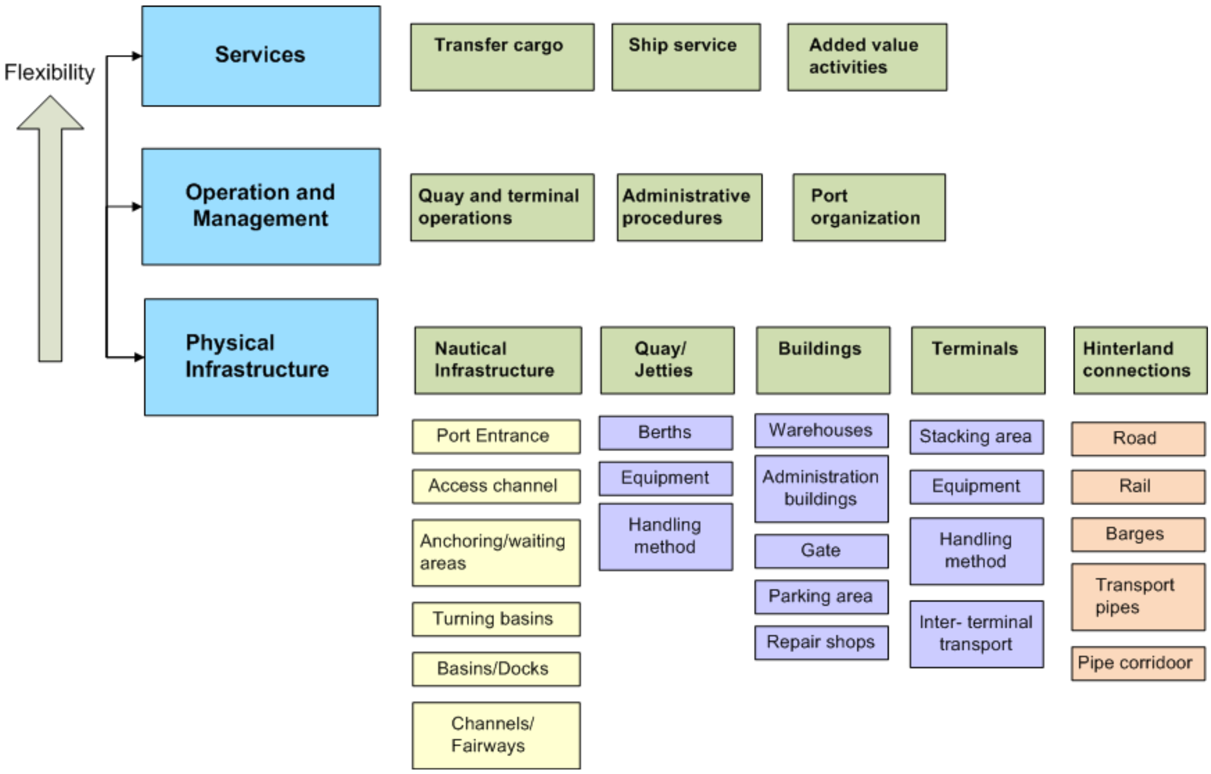

Figure 1. Three-layer inframodel of a port

Some examples of managerial flexibility in the lowest layer are: investing in new infrastructure (with the flexibility to phase, defer, or abandon a project), or choosing another alternative (such as intensifying area use, increasing productivity, changing existing policies or influencing demand). This flexibility is useful early in the development process, when more opportunities to incorporate flexible options in their designs are available to developers. The physical flexibility must facilitate flexibility in operations and eventually result in flexibility in services provided.

In the second layer, consisting of operation and management, flexibility can be introduced in the organization, in procedures and regulations, and in contracts and operations. For example:

- formulating requirements at the level of output specifications and functional requirements, so that that there is flexibility to be innovative and come up with satisficing[8] solutions within the prescribed requirements;
- building flexibility into the terms and conditions of a contract (concessions, guarantees, subsidies, collaborations), thus allowing participants to react to changes that could occur during the implementation stage.

[8] Satisficing (Simon, 1969) is a decisionmaking strategy that attempts to meet criteria for adequacy, rather than to identify an optimal solution.

At the third level (services), flexibility is available in the type(s) of cargo and the volumes handled. For instance, in certain situations, economics and demand can require flexible terminals able to accommodate a wide variety of products. Similarly, a low berth utilization rate at a single-user terminal can provide impetus for multi-user facilities.

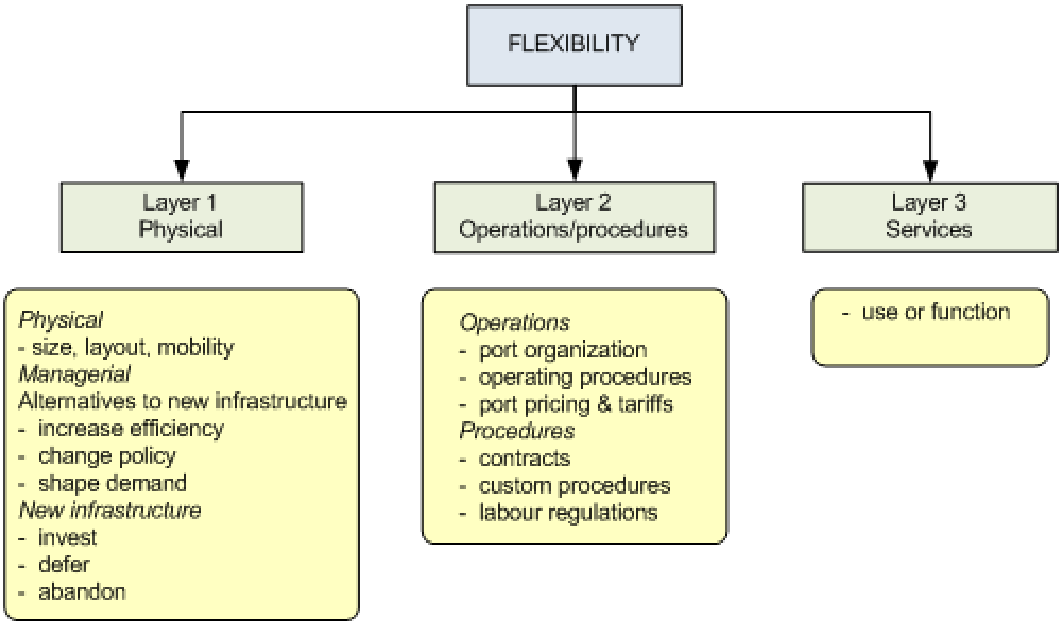

Figure 2. Flexible options available at different levels of the inframodel

4.5. Strategies for flexibility

A flexible option is a means to realizing a strategy; the strategies can be applied to deal with uncertainties. The strategies available to port planners can be categorized depending on the timing of investment and the resulting efficiency of the system (see Figure 3). The four categorizes of strategies are: no flexibility, just-for-now flexibility (expensive and inefficient), just-in-case flexibility (expensive), and just-in-time flexibility (ideal if feasible). These are discussed below, with examples from the port sector.

The *no flexibility* option results in low efficiency of a system and can lead to obsolescence in the face of uncertainty. A tailor-made design based on fixed specification or optimized for a single user that lacks adaptive attributes is an example of infrastructure with no flexibility. Most of the older port projects exemplify this.

Just-in-case flexibility refers to building in margins in the design of system components so that the system can be adapted in response to changed requirements. This is also known as giving an engineering structure more robustness against underestimated, unforeseen, or unknown circumstances. This strategy is expensive and a waste of resources if flexibility is not utilized, otherwise it proves to be very cost-effective. In the 1990's, when major investments in container terminals were being carried out at the Maasvlakte, fourth generation ships with a draught of 12.5 meter were current. However, in the PoR, the ECT/SeaLand terminal at the Europahaven, as well as the Delta 2000-8 terminals at the Amazonehaven, were provided with deeper drafts (for future ships) and deeper quays which could accommodate heavier cranes for future ships at an extra cost. This is an example of just-in-case flexibility, which has allowed the berthing of much larger than expected vessels, including an 11,000 TEU container ship in 2008.

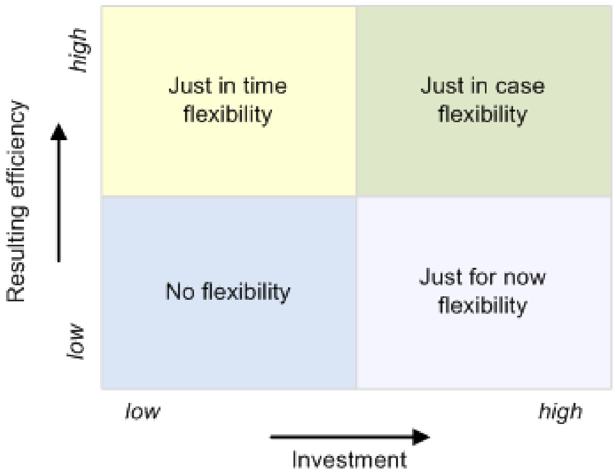

Figure 3. Flexibility options in port design

Another example comes from ports in the UK from the 19th and early 20th century, such as Southampton, Immingham, Newport, and Tilbury. These were provided with dimensions that have allowed those ports to meet the challenge of rapidly expanding ship sizes and to prosper. Their great natural advantages, ideal locations, and densely populated hinterlands have been fully exploited in pursuing a policy of enterprise and foresight (Bellis, 1990). Many other ports and docks with limited dimensions (no flexibility) are now closed.

In 1905, following the design of de Rijke, a Dutch engineer, the Port of Osaka in Japan was converted from a river port to a seaport at an enormous expense. This laid the framework for the present prosperous port, which is currently a part of the second biggest urban and industrial zone in Japan (Takamura, 1990).

Just-for-now or ad hoc response to changes in requirements entails high costs to change the system. This is applicable when the existing system is not adaptive (has no flexible options). In 1967, the former director of the Port Rotterdam, after a visit to New York, brought in the first container line for Rotterdam. The port reacted to this development in a very flexible manner, by converting the Eemhaven, then under development as a general cargo port, into a container port (which involved lining the mouth of the Eemhaven, filling in a part of the Princes Margriethaven, expansion of ECT, and deepening the existing quay wall of Pier 7 in Waalhaven). This is a typical example of just-for-now flexibility. (Today, PoR is the biggest container port in Europe).

Just-in-time flexibility is exercised when there is most need for it. This type of flexibility requires careful monitoring of the environment. It is efficient but difficult to implement in the lower layer of the inframodel. It is cost-effective — there is no wastage of resources, especially if the system is adaptive — and in times of high volatility, this type of flexibility is most desirable. Mulberry Harbour was constructed in 1944 in Normandy. It was a flexible port that could be taken anywhere, up-anchored, and moved to another site if necessary. Due to its ability to have its configuration changed, it could deal with both military and civilian vessels. The mobility, flexibility, and versatility that were the themes of Mulberry have not been perpetuated in any noticeable measure (Bellis, 1990). This is an example of just-in-time category.

The Charleston coal terminal was built during the 1979-1981 coal crisis. Even though the Master Plan did envision an ultimate 'super' facility, the company chose a staged approach involving a small initial investment. The subsequent stages were to be implemented only if the business volume developed. When the coal crisis subsided, Charleston emerged as one of the few ports without a huge debt (Yu, 1989). Just-in-time flexibility with an eye on basic economics and rapidly changing needs proved to be invaluable.

'Real options', representing flexibility that can be exercised on demand, also belong to this category. An example is a quay wall of modular construction that can be upgraded or downgraded in size when required (the extended lifetime of the quay and high utilization would justify calling it a "low investment" alternative in the long run).

4.6. Drivers, barriers, and enablers of flexibility

Most of the current trends in the port sector, discussed in Section 2, can be categorized as barriers, drivers, or enablers of flexibility (Figure 4).

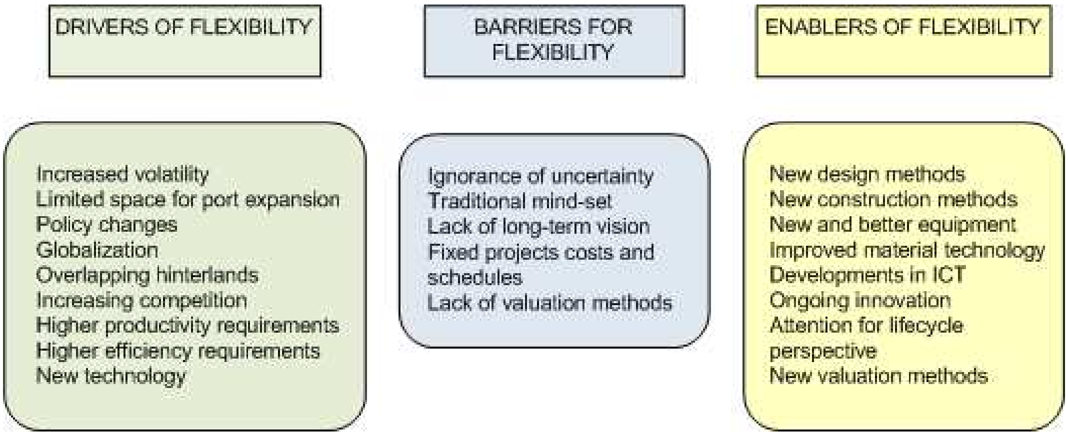

Figure 4. Drivers, barriers, and enablers of flexibility

4.7. Perceptions of flexibility

Flexibility is not always desirable and it generally comes with a cost. A brief discussion of the perception of flexibility in the eyes of different stakeholders in a port development project follows.

Customers: The wishes of the customers in the port sector are directed more and more towards flexibility. This is not only limited to the waterside of a port, but extends to flexibility in the whole supply chain/ chain of goods transport. It should be possible to handle and transport goods at any random moment. Moreover each customer has his own specific requirements to be accommodated that are not a part of a standard procedure.

Planners and designers: Engineers design to fixed criteria, and engineering is based on standards and norms. Yet, port planners and designers often tend to take flexibility into account in their Master Plans and designs purely on the basis of intuition: modular layout of terminals; extra reinforcement in concrete superstructures; or extra wall thickness in steel structures (waiting time of ships in case of collision requiring repairs to the quay wall weighed against extra material costs). However, this flexibility is seldom formally addressed and included in the project evaluation.

Contractors: Project management puts a lot of emphasis on assuring conformity to time, budget, and scope constraints. Flexibility is generally seen as a threat to delivering the project on time and within budget. The general notion is that, in order to maximize efficiency, projects needs to be clearly defined in the front-end phase and executed according to the plans. Too many design alternatives or changes in designs mid-way into a project due to scope change or unexpected situations are seen as a risk.

Decisionmakers: Decisionmakers who generally regard uncertainty as negative are now beginning to realize that this very uncertainty can offer opportunities and competitive advantage. With the advent of tools such as real options for investing in uncertain times, flexible options can be included in their projects and uncertainty can be exploited. However, managers have to struggle to balance flexibility and continuity, as well as to prioritize among different (and often conflicting) forms of flexibility.

In conclusion, flexibility is more valued by the stakeholders that have a responsibility for the overall profitability or societal benefit of a project, compared to those who are only responsible for the cost side of the project (e.g., a contractor). This situation can be changed if stakeholders on the cost side are given room to deploy flexibility as well as take advantage of it (by being allowed to keep a part of the benefits).

5. A planning framework incorporating flexibility

5.1. Adaptive Port Planning

Adaptive Port Planning (APP) is an integrated planning method that offers a unified approach for strategic planning and risk management, and guides planners to systematically deal with uncertainties that appear over the lifetime of an infrastructure project. APP is based on Walker et al. (2001) and Dewar (2002). It results in a flexible plan – i.e., a plan that anticipates and adapts (flexible options are embedded in the plan for adapting it). Subsequently, the resulting plan will perform well no matter what future occurs. A description of APP can be found in (Taneja et al. 2010a). Some of its features are that it:

- considers a range of plausible futures;
- takes into account the full range of uncertainties, including those external to the system, those with respect to the system model, and those associated with stakeholder valuation of outcomes;
- includes pro-active actions for responding to expected and unexpected changes (before and during the project);
- systematically guides the planner or decisionmaker to look for flexible options;
- monitors the external environment for developments as well as the result of actions taken to reduce the uncertainties (likelihood of occurrence or its impact);
- includes a method for valuing flexibility, so that the cost-effectiveness of the flexible option can be demonstrated;
- reduces surprises with respect to time and budget;
- helps to increase the speed of decisionmaking, thus working as an enabler of flexibility;
- demonstrates the cost-benefit of the risk management effort;
- forces decisionmakers to be more explicit about the assumptions underlying their plans;
- provides a way to handle complexity;
- reduces the consequences of complexity;
- provides structure in the preparation, implementation, and exploitation phases of a project;

- routinely examines assumptions on the basis of new knowledge from the strategic environment;
- is a continuous and dynamic process.

In short, APP provides a generalized framework in which to address decisionmaking under uncertainty.

5.2. Real options

As discussed earlier, value can be created in a project through building in physical options that can be exercised in case of changed functional requirements, or by incorporating flexibility in different processes in a project that allow adaptation to changed circumstances. Identifying, evaluating, incorporating, and managing real options is an important step in APP (Taneja *et al.*, 2010b). Real Option Analysis (ROA) is a systematic and integrated decision analysis process used to evaluate investment projects that are facing uncertainty. It is a technique that originated in the financial world, and is now being applied to real investments. It uses DCF methods as a building block, and integrates decision trees into a sophisticated framework that provides analysts and decisionmakers with more meaningful information. Flexibility usually means extra investment costs, but a payback may be expected in time. Hence financial tools such as ROA that can quantify flexibility are required to justify its incorporation in projects. A vast amount of literature is available on real options. Some of the pioneering work on ROA is being carried at the Engineering Systems Division of MIT (de Neufville, 2007; Greden, 2001; Nilchani, 2005).

6. Conclusions

A port represents a major infrastructure investment with a design life of several decades that needs to accommodate today's needs as well as tomorrow's. The complexity of a port system will always produce unexpected effects, and the dynamic nature of the system will always create new challenges to the design. The prevailing volatility means uncertainty in demand forecasts and future technology, and uncertain policies. Moreover, the shifting role of a port from nautical, cargo handling, stacking, and distribution functions to being a multimodal node in the logistic chain has led to changing trends.

Meanwhile, ports worldwide are either investing in new infrastructure or modernizing existing infrastructure, and are implementing improvements in facilities in order to keep up with the competition. Port development projects entail elements such as port planning, design, and economic evaluation. The standard practices are not appropriate for uncertain times. Strategic planning and risk management are treated as independent activities, and practiced in different time frames. The decisionmaking process is linear, and cannot benefit from new information as it appears. A systematic and integrated approach to the planning of a port project is missing. The standard techniques of economic analysis do not value flexibility in projects and justify its extra cost.

This clearly demonstrates the need to revise best practices. Complex infrastructure engineering projects require flexibility to be able to deal with uncertainty. Therefore, port planning needs to move from optimal designs to flexible designs, from anticipating risks to monitoring the environment, from operative Master Plans to directive planning, from strategic planning (aided by risk management) to an integrated method such as Adaptive Port Planning. Project evaluation needs to shift from traditional techniques to real option methods valuing flexibility. In short, innovative methods and techniques from the diverse fields of engineering, finance, and management must be applied towards the single objective of achieving flexibility in port planning and design.

Flexibility coupled with innovation will enable a port to develop strategies to meet the current as well as the future needs of the enterprise and its stakeholders (while protecting and sustaining human and natural resources).

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