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PORTS AS SUSTAINABLE COMPLEX SYSTEMS

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Abstract

Ports and harbours are very large infrastructure projects which have great impact on the community, environment and the economy of a country. Ports are not only a vital lifeline link between water-side and land-side traffic, but are also sources of national wealth, pride and concern. Stakeholders now want requirements to be described in a creative, rigorous, and policy-relevant manner and for critical issues such as sustainable development to be incorporated into developments. This paper looks at the issue of sustainable development for ports and harbours as being one of managing complexity and considers how wider requirements may be accommodated.

Most of the problems related to sustainability and sustainable development are typically complex and inter-related. It has been shown that the more complex a system the harder it is to manage, but by having insights into the causes of complexity in systems enables decisions to be made actions to be taken where otherwise there may be lost opportunities and ultimately reduced profits. Ports have to achieve a harmonious balance between the local community, the environment and economic issues. By applying systems engineering techniques and ideas surrounding complexity management this paper looks at the designing and subsequent management of ports & harbours and in so doing to develop clearer strategies. Research work into airport processes is used to gain insights into potential approaches for the management of ports and harbours.

Keywords: Systems, sustainable development, ports and harbours, complexity.

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INTRODUCTION

Ports operate within an environment that is driven by natural processes such as tides, currents, and climate, as well as marine biology, society and man-made processes. Within the last six years the literature shows that there has been a rising interest in environmental issues relating to ports and harbours. Port activity is coming under scrutiny, both in terms of capital projects and ongoing operations. For example, the European Commission's transport policies are now expressed largely in terms of their potential impact on the environment and expected levels of pollution. In 2002 David Jamieson, the UK minister of shipping, stated that modern ports must be '*successful, sustainable and safe*', (DTLR, 2002). There are also a number of European research institutes and international organisations that are promoting the sustainable development of ports such as "Ecoports", "Espo", "New! Delta" and "UNEP – regional seas programme".

Ports are traditionally designed and built based on the specified maritime and channel design, quay design, the expected port operations and cargo handling, the terminal layout, and also to the expected marine traffic and type of cargo. Simulation models are used extensively for the analysis and planning of ports, and there are a wide range of published research reports. Existing literature includes simulation models of full container terminals (Nam et al., 2002; Agerschou, 2004), container movements to and from trucks (Sgouridis et al., 2003) and to and from vessels (Sgouridis et al., 2003), vessel traffic (Pachakis and Kiremidjian, 2003; Asperen et al., 2003), and ship handling at the port (Bruzzone et al., 1998). Arena software (Kelton et al., 2004) is a well known simulation package, and is used extensively in commercial operations, including port planning and analysis, (Sharpe et al., 2005; Goldsman et al., 2002).

We are however witnessing an inexorable increase in complexity in all spheres of social life and problems relating to sustainable development are typically complex, interconnected and 'messy'. 'Messy' problems are challenging traditional approaches to problem solving, such as reductionist approaches. Ports, and the problems they seek to solve, are becoming more complex. It is not possible to design part of the port system in isolation without considering the problem and solution as a whole. Simulation models can accommodate the dynamic or transient effects seen in port and shipping operations in unexpected situations, such as adverse weather conditions or equipment breakdown, however they are limited to relatively straightforward problems and cannot cope with complex, inter-related factors such as, for example, the degradation of the local environment through dredging, loss of support from the local community, the effect of more extreme and unpredictable seasonal variations, and the potential effects of a new development on the physical and biological marine environment. Many of the emergent behaviours from these complex relationships are unknown, such as not being able to guarantee cargo handling efficiency, i.e. demurrage payments, which is a characteristic of a complex system. Simulation models and other predictive methods are based on data where 'outliers', i.e. unusual operations are removed from the data sets due to the possibility of creating misleading results, (Khatitashvili et al., 2006). These models fail to provide insight into the complexity of current port systems, of the potentially complex and hidden linkages established between system inputs and system elements.

Complexity is probably the most significant characteristic of all aspects of our lives and of our global society. But even though the rapid increase of complexity is a recognised problem, complexity isn't being used in decision-making and management. Sustainable development is probably not impossible without due consideration to the phenomenon of complexity. Indeed it is common sense to assume that there are limits as to how much complexity a given system may be capable of before becoming unstable and potentially fragile.

Understanding and defining the problem correctly is crucial when defining a realistic representation of a system. It's also clear that new outcomes will not result unless new procedures are employed. We must then look to improving the way we look at problems and the processes by which things are made, (Godfrey, 2006). One approach is to adopt a holistic perspective and to adopt a methodology that enables the system to be driven from the requirements of the key stakeholders. Systems thinking provides such a framework for problem solving. Recent research has shown that a systems approach can define a wider problem boundary than those limits traditionally adopted by engineers, (Fenner et al., 2006). Systems thinking requires whole-life thinking, i.e. consideration of the implications of every decision, and recognition that what happens in one part of a system affects every other part. Thus this can then lead to the creation of a wider design space in which more holistically conceived solutions can be formulated to any given problem, (Fenner et al., 2005).

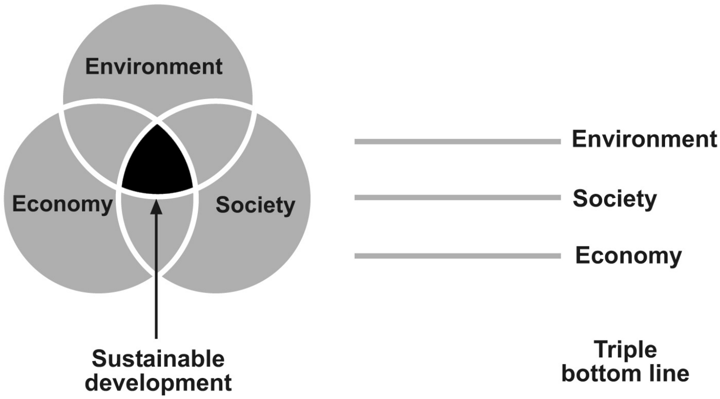
Systems thinking also has the potential to capture complexity. The aim of this paper is to investigate the use of systems engineering techniques and new ideas surrounding complexity management for the designing/managing of sustainable infrastructure systems, within the context of ports and harbours. A key idea being brought to the research study will be to investigate whether comparisons can be drawn between airports and ports and the potential use of distributed data resources/assets can be used for active and sustainable management of systems.

SETTING THE SCENE

Sustainable Development

There has been an enormous amount of work on issues relating to sustainability since the rise of environmental consciousness in the 1970s (Mazmanian and Kraft, 2002), and by far the most common usage of the word "sustainable" is in combination with the word "development", (Mazmanian and Kraft, 2002). According to Parkin et al., (2003) there are over 200 definitions of "sustainable development", and the term has now penetrated planning and various other academic disciplines, and has become one of the pervasive icons of modern times, (Jabareen, 2004). Some researchers see sustainable development as an emerging meta-discipline that is beginning to define a whole new subject area, (Mihelcic et al., 2003).

Fig. 1. Sustainable development: Venn diagram & triple bottom line.



As already indicated definitions of sustainable development vary widely (Jabareen, 2004; Robinson, 2002), however most call attention to the need to maintain resilience in environmental and social systems by meeting a complex array of interacting, environmental, social and economic conditions, (Swart et al., 2004). These dimensions have complex inter-linkages and are often conceptualised as overlapping circles in a Venn diagram, see Fig. 1, and have also been characterised as the Triple P concept: Planet, Profit and People (Serageldin et al., 1994), which emerged out of the Brundtland report on sustainable development (Brundtland, 1987), and is characterised by industry in particular as 'triple bottom line' accounting.

Complexity

Complexity science is a subject that is relatively new and still is compared to more established sciences such as physics, biology and chemistry. With the establishment of the Santa Fé institute in New Mexico in the US in the early 1980s a new research movement emerged which laid the basis for complex systems theory (Holland, 1995; Kauffman, 1995), and this new research is currently attracting a great deal of attention, (Rotmans, 2005). The range of potential research problems and their very diversity can lead to confusion. From one end of the problem domain we might be considering a large software system such as an air traffic control environment, or on the other how Darwinian natural selection accounts for intricate structures such as an eye or kidney, and why rural families in Bangladesh still produce an average of seven children, (Waldrop, 1992).

Most of the systems related to sustainability and sustainable development are typically complex and inter-related, (Brown-Santirso and Peet, 2005; Holmberg and Karlsson, 1992; Giallopin, 2003; Cabezas et al., 2005). These include ecosystems, economies, social systems, and industrial and production systems, (Cabezas et al., 2005). It has been shown that the more complex a system the harder it is to manage. Ports have to achieve a harmonic, complex balance between the local community, the environmental integrity of their processes, and progress economically. One key set of ideas that might be of relevance to all complex systems which various researchers have shown, is that when system's complexity reaches critical levels, which happens over time, systems can become fragile, and therefore vulnerable when exposed to changing and uncertain environments. Conversely the more complex a system the more functional potential that a system posses. In these terms then there are perhaps conscious trade-offs to be achieved in man-made systems, and in particular there may be ways of managing sustainability as a function of complexity. When sustainability and sustainable infrastructures is viewed from the perspective of complexity there may be novel approaches that can be applied to practical systems.

Systems Thinking

Within the last five years there has been a drive by the UK government, the Institution of Civil Engineers (ICE) and the Royal Academy of Engineering to increase the awareness of systems approaches within the Civil Engineering sector, (The House of Commons, 2004; RAE, 2007; Bourgine and Johnson, 2006). There are several examples of its potential benefits in highly published infrastructure projects, and a small group of researchers who are also advocating its use, (P Jowitt from the Scottish Institute of Sustainable Technology; Karl-Henrik Robert from the Natural Step; K Marmen from the Oakland Institute; The Sustainability Institute in Hartland, U.S.; The Polyurethane Industry). In various literature resources, systems and their complexity are now viewed as an essential 21st century science (Living Roadmap for Complex Systems Science), and are predicted to be at the heart of the future Worldwide Knowledge Society. There is also now a "living roadmap" for systems in order to help consultants implement what are considered "big ideas" into European projects, (Living Roadmap for Complex Systems Science). Additionally, since the first major attempt to teach systems was in 1950 at MIT by Gilman, there are now numerous systems engineering centres throughout the world and new systems courses.

The core of systems thinking requires whole-life thinking, i.e. consideration of the implications of every decision, and recognition that what happens in one part of a system affects every other part. Within a sustainable development context this primarily means understanding that the three elements comprising sustainable development are all inter-related and cannot be considered in isolation, e.g. an alternative electricity source such as wind energy installed in a plant must not negatively impact the bottom line, and a new port development cannot be built in an area where air quality and noise emissions negatively impact a local community. Systems approaches begin by understanding the broader system within which problems occur and the principles governing success within that system. This upstream approach means problems are addressed at the source and are turned into opportunities for innovation and business success.

LESSONS FOR PORT PROCESSES FROM AIRPORT MANAGEMENT

The principle operations of a marine port and an airport are fundamentally similar. Both need to dock vessels, offload and load cargo, and are dependant on weather and other indirect social and environmental influences. Perhaps the key difference is the involvement of people, the need for safety, and the shorter times of the key processes. Despite these differences there are perhaps lessons to be learned. A recent study into stress levels of aircraft traffic controllers approached the problem from a holistic systems perspective. The safety of air traffic systems is directly related to the workload and the availability of resources necessary to manage the traffic. For example, a given number of air traffic controllers can efficiently and safely manage only a certain maximum amount of traffic. The goals of the study and ensuing analysis were to identify non-intuitive but distinct patterns of behaviour which governed the overall airport-system processes, and to examine external influences on the airport system from a holistic systems and complexity perspective, and to potentially, in the long-term, outline design and management improvements for the sustainability of airport infrastructure. Insights were gained into airport processes and knowledge models were built from process data. A complex systems analyser (CSA) was used for building the knowledge models from the data and for analysis purposes. The details of this analysis will be discussed in further detail below.

Methodology

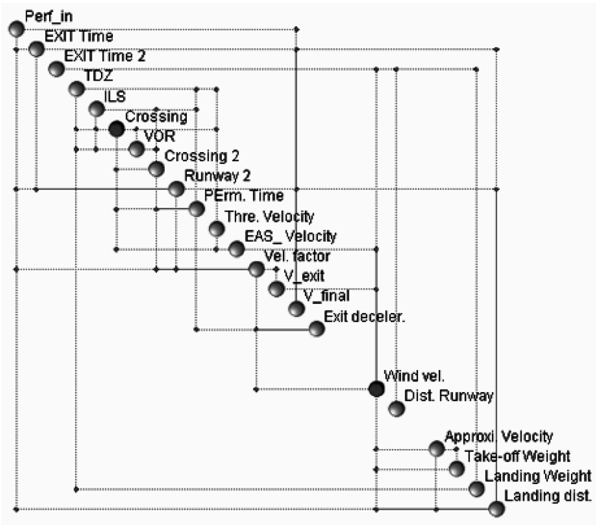
The CSA offers an alternative approach to data analysis, and an entirely novel one, this is to build fuzzy cognitive maps (FCMs) from measured process data characterising the system domain. This novel approach means deriving FCM models and node relationships purely from process data. Fuzzy cognitive mapping is used as a tool for handling imprecise, or ill defined "fuzzy" problems.

The CSA establishes an absolute measure of complexity and this provides a sufficiently robust methodology to allow comparison of similar systems. The software extracts the modes which represent the possible patterns of behaviour of a given system and represents each as a fuzzy cognitive map. System variables are displayed along a diagonal while significant relationships between the variables are represented by 'connectors' located off the diagonal. Hubs, which are inputs with a large amount of connected variables, are indicated in red (an input) and blue (an output). Each relationship establishes, *de facto,* a rule of the type 'if A then B'. The rules being fuzzy. Therefore, a mode in practice corresponds to a set of interrelated fuzzy rules in which certain variables may affect one or more variables at the same time.

Results

Fig. 2 below shows a fuzzy cognitive map from time-series data for the relative movements within the airport and their potential modes of behaviour respectively. Analysed variables are arranged along the diagonal of the map, and 'connectors' off the diagonal show the significant relationships between the variables.

Fig 2. FCM for air traffic management.



As the complexity of a system increases, the number of connectors between the nodes, i.e. the inter-relationships between the variables, increases rapidly. The large red hubs indicate where the system is most vulnerable, and difficult to manage. Analysis reveals that wind velocity appears as an influencing factor of significance within the system, i.e. as the wind increases the workload on the air traffic controllers increases. This data analysis was confirmed by interviews with operators and supported common knowledge and intuition, but which had previously not been formally recognized as a key process variable.

In addition, based on real-time traffic data, complexity may be measured and used to establish and monitor critical traffic density against an agreed baseline. This information is seen to help set workload and also to identify critical periods at different airports in a given traffic sector. Critical complexity of air traffic becomes measurable and therefore manageability and overall operational safety is increased. Knowing "a priori" of critical system complexity, and its causes, provides operators with a powerful new tool for robust operational performance.

Discussion

In the airport example, the primarily concern is the methodology of analysis and the opportunities presented by the novelty of this approach. By taking a wider systems view, say than those immediately obvious measurements such as aeroplane exit time and entry time, landing distribution and runway number, revealed critical system elements previously not focused upon, and most importantly identified critical points and hubs within the process. It was also possible to see how complex the processes are within the airport system and identify the limits of sustainability within that system.

In the case of ports and harbours, we want to look at all the processes within a port system and to find the data that is either available or can be measured to characterise those processes, and then to look at the links and relationships of significance. A range of measures could be analyzed say from dredging metrics to ship movements, cargo handling rates, pilot hours, container movements, no of staff, no of maintenance interventions, rail exports, road movements, exports, and anything else that can be measured and which stakeholders would feel relevant to port operations and that would characterize their processes.

The systems side of the analysis means drawing the system boundaries as widely or narrowly as needed to define the problem, and looking at, and learning from the encapsulated real world events, such as the rise in sea water levels, the loss of marine habitats, and freak weather patterns. The idea is not to look at only one focused part of the system, say the harbour silting model, but to try and look at the system as a whole, and all the interconnecting elements in order to try to discover emergent properties and also the variables that might influence the behaviour in ways not fully apparent at the present. Traditionally this type of analysis is not pursued because there aren't the tools available for this kind of work and it's also very hard to start adding "soft"/"fuzzy" variables into hard models.

In summary, the opportunity here is to use data metrics to characterise a system and use the knowledge model to gain system insights. In this approach the complexity of a process can be captured, and insights can be derived from models. This process does not try to build theoretical models, but rather establish working practice from experience and in a way that enables insight, learning and future planning.

CONCLUSIONS

The scale of the new global challenges demand an alternative approach to engineering problem solving. Systems engineering is a process of continuous learning about the systems in question and their interactions with the dynamic environments with which they are connected. Port authorities are necessarily engaged in a complex global role within business, environment and people. Engineering for sustainable development requires whole-life thinking and consideration of all the implications of every decision.

Systems thinking has much to contribute to improvement in sustainability by helping to create a line of sight from individual activity to emergent properties. A holistic systems approach is a potential way of incorporating real world events into port processes and thus of managing sustainable development. In this context sustainability is seen as directly related to critical system complexity, i.e. a system reaching unmanaged critical complexity will by definition be unsustainable.

Sustainable development presents new problems for port authorities while at the same time presenting opportunities. Solutions offer massive commercial and social gains. The key idea in this paper is to treat sustainability as a branch of complexity science and to bring tools and technologies already available from other fields and to use them as an adjunct to systems thinking.

FURTHER WORK

The next step will be to use port instead of airport data. The challenge will be to convince the various short- and long-term stakeholders that will own various processes and data sets to be willing to contribute to a total system view that will ultimately benefit all parties.

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