A System Dynamics Approach for Strategic Analysis of Project Portfolio Interdependencies

Abstract
Understanding project portfolio interdependencies is essential in order to manage projects in complex and dynamic environments. Project environments across the globe are becoming increasingly complex, creating heightened challenges for project management (PM) and project portfolio management (PPM). Current research indicates that organisations globally fall short of understanding how project interdependencies affect portfolio outcomes. The literature on System Dynamics (SD) suggests that SD may be a suitable tool to encapsulate the "bigger picture" of PPM interdependencies. This research applies a client interactive approach using SD modelling techniques to represent interdependencies within a project portfolio. A case study was conducted with the Royal Australian Navy (RAN) to investigate SD as a potential tool for the management of project portfolio interdependencies The outcomes of the case study suggest that SD has the ability to challenge an organisation's perceptions of their project portfolio interdependencies and to enhance strategic decision-making capabilities.

Keywords. Project Portfolio Management (PPM), System Dynamics (SD), Project Interdependencies, Royal Australian Navy (RAN)

Introduction

Project portfolio management is an integral tool for of many organisations in today's ever expanding business markets. A primary goal of PPM is to "ensure that the collection of projects chosen and completed meets the goals of the organisation" [**1**]. Projects contain constraints such as time, costs, resources and other factors that interact with each other and require specialised techniques to support strategic portfolio decisions. These constraints can be viewed as intricate networks with inter-related dependencies. The research reported in this paper investigates system dynamics (SD) as a potential tool to improve the understanding and management of project portfolio interdependencies and to enhance strategic decision-making processes.

Project Portfolio Management

Project portfolio selection has been defined as "the periodic activity involved in selecting a portfolio, from available project proposals and projects currently underway that meets the organisation's stated objectives in a desirable manner without exceeding available resources or violating other constraints" [**2**]. The management of project portfolios is crucial to the success of organisations and it is the relationships between projects within a portfolio that greatly impact on the success of organisational outcomes.

Innovation has been recognised as the key driver of economic growth in developed nations as firms have become progressively more project-based highlighting the increased interest in the study of PPM in recent years [**3, 4, 5**]. The ability to maintain a balanced project portfolio that is aligned with strategic goals stems from the processes contained within PPM that assists organisations to manage their project portfolios using a variety of tools and methods that are capable of generating and evaluating project information [**6, 7**].

PPM is a complex, yet rapidly growing field for innovation and research. Through awareness the understanding and development of new methods can be applied to PPM research in order to maximize the benefits across organisations globally. The management of project portfolios is enveloped within the following key issues: the collection and prioritization of high value projects, developing a defined balance of projects across the portfolio and balancing resourcing constraints across all projects [**6**].

Management of PPM Interdependencies

Project interdependencies are among the many factors that must be considered in PPM decisions [**8**]. A project interdependency exists when one project is dependent on other(s), for example through the need to use the end result of another project, the need to incorporate the capabilities and knowledge gained through another project, or the need to wait for scarce resources until they are released by another project.

The literature suggests that there is a need for better strategies to manage project interdependencies to develop successful cross-communication capabilities [**9**]. Resource dependencies are often addressed by scheduling optimisation systems [**10**], however the required numerical input is not considered useful in PPM environments due to the extensive volume required by systems that does not provide effective feedback. Numerical methods have also been addressed regarding NPV and other discounted cash flow analysis that are based on time-cost performance triangles that aid in PPM in the short-term, but fail to determine the long-term value of project portfolios due to uncertainty within markets [**11, 12**].

The management of project portfolio interdependencies is a difficult and challenging task that faces numerous obstacles. The key issues encountered include the multi-level interdependencies amongst projects, uncertainty within the portfolio, strategic decision making processes, resource availability, project termination capabilities and the vast number of variables impacting project portfolios [**13]**. However, there is a gap in the literature highlighting the need for better tools and methods for the management of project portfolio interdependencies to enhance organisational outcomes.

System Dynamics: A New Approach

Forrester pioneered system dynamics during the 1960s as an analytical modelling technique [**14, 15**]. Sterman quoted, that “the fundamental principle in system dynamics states that the structure of the system gives rise to its behaviour” [**15**]. Systems thinking is a scientific field of knowledge that emphasises the need to understand change and complexity through the interactions and relationships of different components in a system by studying the dynamic cause and effect over time [**16, 17**].

Individual components in a system do not contain the most complex behaviours, but rather the interactions of the components contain the most complex behaviours [**15**]. To analyse the interactions of components in a system the feedback structures must be understood through analysis of cause and effect over time. By understanding feedback loops system dynamics can be put into action through the assessment of issues from multiple perspectives. The key goal of system dynamics thinking is to challenge initial perspectives and consider the long-term effects of actions chosen that could possibly impact the environment, society or moral beliefs [**15**]. System Dynamics involves a comprehensive set of steps, which should be undertaken in order to gain the full benefits of the tools provided to achieve successful outcomes.

System Dynamics is a new approach to project portfolio management and the interdependencies that exist within these relationships. Compared to other network mapping tools, systems dynamics offers the opportunity to analyse complex and dynamic problems, which allows organisations to learn and understand their internal systems through a more effective model [**18]**. Traditionally applied to manufacturing and financial systems, system dynamics is being re-modelled for business systems across varying fields. System dynamics is capable of accepting the feedback loops, nonlinearity and complexity of business structures that traditional methods of network mapping techniques cannot achieve [**19**].

There is the argument that system dynamics is not easily integrated from real-life systems to a simulation model [**19**]. In order to overcome these current problems new methods must be integrated into the current systems that follow clear and concise processes, applicable across various industries. System dynamics has the potential to challenge traditional network mapping tools and implement new models in regards to management of project portfolio interdependencies.

System dynamic modelling offers a systematic process to capture and analyse systems. It is proposed that the application of system dynamic modelling may improve the understanding of interdependencies between projects in complex project portfolios, and therefore may be a useful tool to assist with project portfolio strategic decisions. The following discussion will demonstrate with the use of a case study the potential application of system dynamics as a tool for the management of project portfolio interdependencies.

Case Study: Royal Australian Navy

The Royal Australian Navy (RAN) has a range of complex and dynamic project portfolios. One of the RAN portfolios was used as the basis for a case study to test the validity of system dynamics as a potential tool for the management of project interdependencies within the organisation's portfolio. In doing so, the aim of the research was to discover if the understanding of project portfolio interdependencies could be improved using SD modelling, which in turn could enhance the quality of strategic decision-making and further improve organisational outcomes. The project portfolio studied was initiated in response to the "Submarine Workforce Sustainability Review" [**20**], which outlined twenty-nine recommendations that have now been implemented as projects.

The case study was structured through the development of interviews, email correspondence and thorough research of media sources. For the study iThink [**21**] software was used to develop the system dynamic models. The case study was used to effectively test the validity of system dynamics as a tool for the management of project portfolio interdependencies across the RAN submarine portfolio. System dynamics was used because it incorporates feedback loops, non-linearity and complexity that many other methods and tools are not capable of modelling. It also goes further to analyse 'what-if' scenarios and test forecast simulations as a method of challenging understanding of the problem definition to reveal the underlying behaviours of systems. In doing so, the research endeavours to improve the understanding of the RANs project portfolio to improve the organisations outcomes, such as return on investment.

Method

System Dynamics is used as a tool through the breakdown of a complex process. The following discussion investigates the use of the system dynamics method undertaken using the RAN submarine project portfolio as a case study example.

The main steps of the system dynamic modelling and analysis process include:

1. Problem Articulation
2. Dynamic Hypothesis
3. Causal Loop Diagrams
4. Stock and Flow Models
5. Simulation and testing
6. Forecasting and 'what if' scenarios

Problem Articulation

Problem articulation defines the underlying issue within a system and can involve the impacts of the real world, policies, events, feedback loops, strategy implications and mental modes. Throughout the process of articulating the problem, participants must allow the modelling process to alter their mind and challenge their initial perceptions of the problem [**15**]. The goal is not to model an entire business or social system, but should aim to model the main element of the problem [**15**].

The RAN submarine project portfolio was carefully articulated to break the problem down into key areas that required immediate attention. Twelve of the 29 projects were identified as major problem areas due to their impact on other projects through complex interdependency networks embedded within the portfolio. Each problem area was articulated to determine the major issues recognised, questions that required answering and the key projects that were captured.

Dynamic Hypothesis

The dynamic hypothesis is expressed through representations of cause and effect relationships over time and corresponding statements and is the basic foundation for the building blocks of the SD model [**22**]. It is the basis of the decision making process where a general agreement is developed concerning a quantifiable problem and goal [**23**], which requires participants to question the issues of how a system reacts to surrounding dynamic forces both at the time in question and the long-term future [**24**].

Causal Loop Diagrams

The first step in the modelling of system dynamic structures is the development of causal loop diagrams, which are used to simplify the model and act as preliminary plans of the dynamic hypothesis [**25**]. The use of causal loop diagrams is a powerful qualitative tool in the study of complex problems [**14**], due to its capability to model feedback loops through various cause and effect scenarios [**16**, **15**].

A network of six major causal loop diagrams was developed to illustrate the dependency links between diagrams. To illustrate a portion of the model, the central causal loop for the RAN case study, the 'recruitment task force' model, is shown in Figure 1. The key feedback loops have been recognised to mimic the recruiting task force problem situation that was articulated in the problem definition. The development of causal loop diagrams allowed the project portfolio to be mapped as a means to understand the problem situation and assist in the preliminary investigation of the dynamic hypothesis. The causal loop diagrams clearly show that there is strong evidence of interdependency relationships between the projects identified in the problem articulation.

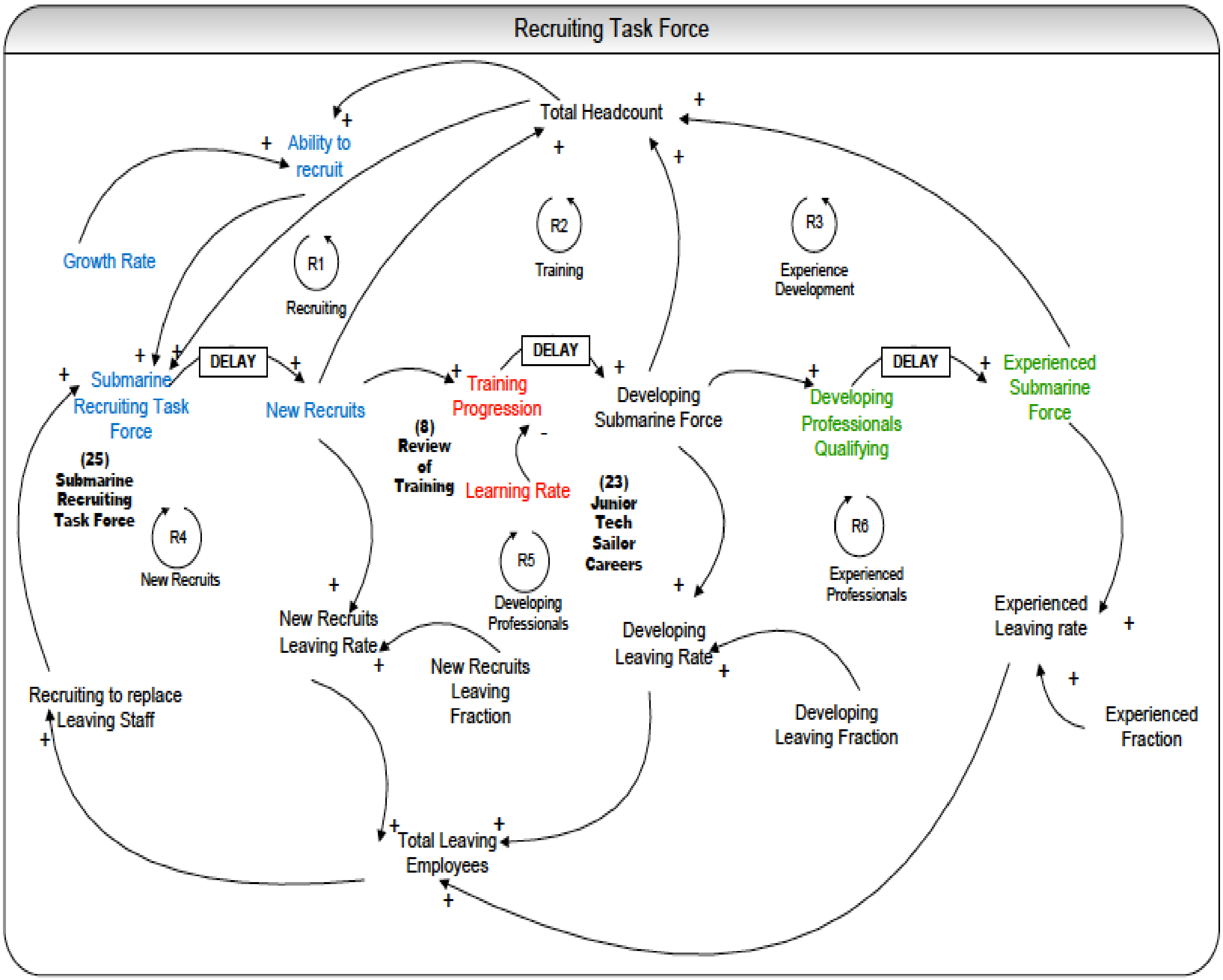

Figure 1. Recruiting Task Force Model Causal Loop diagram

Stock and Flow Models

Building upon the causal loop diagrams, the stock and flow models develop the quantitative aspect of the system dynamics structure with the aid of computer modelling software to mathematically map the flow of information around the system [**14, 25, 16**]. The stocks in the dynamic structure represent accumulations within the system, which are only changed through time integrals of the net rates of flow [**15, 25**]. Stocks can never have causal links directed into them [**15**], but can have causal links directly into flows or constants. The flows within the system represent the rates of change over time between the stocks [**25**]. Constants represent the flow of variables that interact with the causal structure and distinguish the various structures in the system [**15**]. Stock and flow diagrams should be exact representations of the causal loop diagrams, as shown in the Figure 2 example.

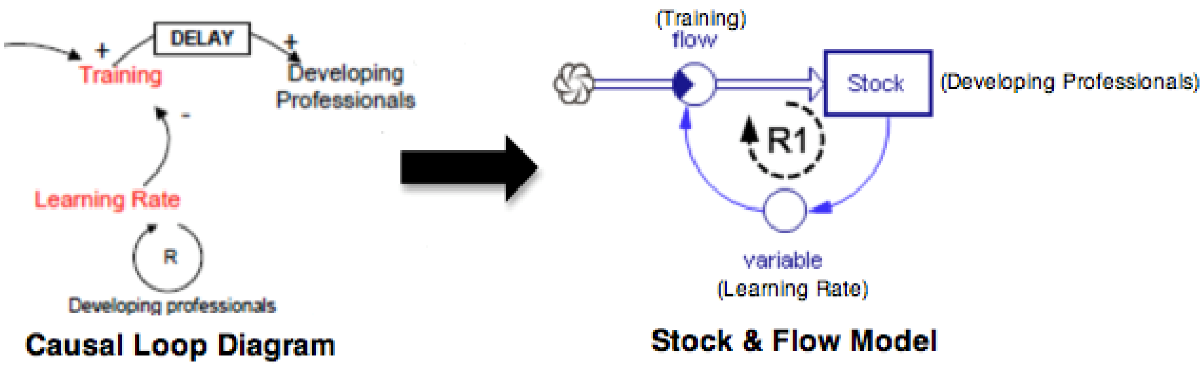

Figure 2. Example of a casual loop diagram mimicked as a stock and flow model.

Simulation and Testing

The development of simulation is essential to the development of the system dynamic models because it allows for the identification of discrepancies, testing of alternative solutions and the clarification of hypotheses to explain the discrepancies. System dynamics simulation development allows for the stimulation of learning and the ability to challenge participant's perceptions of the problem [**15**].

In the RAN case, the fundamental tests that have been chosen for the research encompass a diverse array of assessments that have been undertaken to investigate project interdependency structures. The tests have been narrowed to cross-examine each model, whilst maintaining a dedicated focus across certain project relationships within the portfolio. These key relationships have been recognised through consultation sessions, research and analysis of the RAN submarine project portfolio. In doing so, the key problem areas that were articulated earlier have been tested to determine the validity and suitability of system dynamics to project portfolio interdependency management. A range of tests has been conducted including surprise behaviour tests where previously unrecognised behaviours of the system were identified.

Forecasting and 'What-if' Scenarios

Forecasting analysis was conducted as a long-term measure in an attempt to analyse the future potential outcomes of systems based on human expectation [**15**]. System dynamics does not attempt to predict the future, but is used as a tool to prevent future failures, avoid complications, implement policies and manage change effectively. The forecasting process involves the incorporation of social and political factors that may not have been included in the model and must be recognised during the strategic decision-making process [**15**]. It should be understood that forecasting is not a scientific activity, but rather a social, political and bureaucratic activity [**15**].

"What-if" scenarios allowed the models to be evaluated and analysed plausible strategies that could be implemented into future systems or processes. Managers have the ability to try different policy decisions before making the mistake of investing into a potentially disastrous solution [**14**]. System dynamics provides the capabilities to model various financial "what-if" scenarios that assist management in making effective strategic decisions based on profit opportunities and the most effective paths of investment [**14**]. In doing so, the return on investment in an organisation can be improved through successful outcomes implemented through the use of effective system dynamic models.

Findings

The system dynamic testing, forecast analysis and 'what-if' scenario investigations revealed the strong interdependency links between the twelve projects modelled within the bounds of the RAN submarine project portfolio. All the tests revealed that there were areas for improvement and further investigation was required to reduce assumptions and analyse limitations of the models. The results revealed two key findings that were examined during the surprise behaviour tests and the 'what-if' scenario implementations.

The surprise behaviour test was conducted for the 'Recruiting Task Force' model. The model helps to predict the rates at which the initial 'new recruits' become converted to 'developing professionals' and eventually 'workforce professionals' during their training and development lifecycles. The results demonstrated the effects of increasing and decreasing the variable 'ability to recruit' over a twenty-year period. The behaviour of the system was predicted to increase all workforce professionals exponentially, which was witnessed when the ability to recruit was decreased. However, when the variable was increased a steep drop in 'developing professionals' was observed in the first ten-years before the stock rapidly increased exponentially. The surprise behaviour was examined further to understand why the model exhibited the peculiar results. It was apparent that the model demonstrated that by increasing recruiting efforts significantly that this would initially outrun the ability for 'new recruits' to learn and qualify as developing professionals. As a result, the stock 'developing professionals' would initially decline before accelerating in a positive direction. This was due to the behaviour of the system being counterbalanced as new recruits began to qualify as experienced professionals. The results of the test reveal that the projects to recruit, train and retain professionals possess interdependency relationships that require careful balancing of resources to maintain consistency over time. Thus, the surprise tests revealed circumstances that exist in the real-world system that had not been recognised in earlier consultation discussions. In doing so, the results allowed for further clarification of the project portfolio in order to better manage interdependency relationships to improve strategic decision-making processes.

The 'what-if' scenarios were introduced to prevent mistakes from being made or the wrong investments from being implemented. The models were evaluated to investigate avenues to increase return on investment and generate benefits realisation. In doing so, opportunities were recognised where strategic decision-making improvements could be implemented to improve return on investment outcomes. The first 'what-if' scenario evaluated the 'Detailed Goal Structure' model to determine the effects of implementing a support team to assist training, defence activities and maintenance procedures. The results obtained from the scenario demonstrated the effects of implementing the project 'enhanced support group' within the model 'Detailed Goal Structure'. The findings discovered from the evaluation clearly showed the significance of implementing the support project. As a result, the other projects in the portfolio are positively influenced and are strategically enhanced to increase their return on investment. These projects include crewing of submarines, training of new recruits, the goal, engineering processes and benefits realisation. The 'what-if' scenario provided a foundation to question the portfolio and test the interdependency relationships between the projects. By doing so, the project portfolio could be better understood in order to increase strategic decision-making, which in turn improved the return on investment generated by the projects.

Hence, the findings obtained from the evaluation of tests, forecast analysis and ‘what-if’ scenarios allowed the system dynamic models to be carefully analysed against strict criteria. Each test allowed all of the models to be broken down in order to further understand the interdependency relationships within the portfolio and areas for improvement. The forecast analysis provided a means to study the long-term implication of policies to prevent failures, complications and implement change management. The ‘what-if’ scenarios went a step further and tested the implementation of plausible strategies within the project portfolio to avoid the mistake of making wrong investments. In doing so, all of the methods of evaluation provided a means for better understanding the interdependency relationships within the project portfolio. As a result, the strategic decision-making processes could be improved to enhance the organisational outcomes.

Conclusions

The application of system dynamics as a tool to improve the management of project portfolio interdependencies is new and has not been implemented before in industry or academic research. The concept was first introduced to Naval executives who felt that the use of system dynamics as a tool for PPM was “very relevant to the Naval defense force”. It was commented that the “use of system dynamics as a tool would support the workforce structures and compliment current workflows”. The ability to reduce costs and effectively manage the project portfolio interdependencies of the submarine workforce are critical factors that require tools to improve strategic management processes. The research has provided a well-structured foundation for the application of system dynamics to improve the understanding of project portfolio interdependencies. However, the limitations and assumptions must be taken into account and understood as a means to improve the models in the future. The key limitations include software, timing factors and the availability of information. It is important to recognise these problems as a means to further research and develop system dynamics as a tool for PPM. In doing so, the models will not be misused and instead will be addressed appropriately, which could potentially develop the tool as a commercially viable solution.

Hence, the research has attempted to investigate the suitability of system dynamics as a new tool for the improved understanding and management of project portfolio interdependencies. In doing so, the research has taken a step-by-step approach to the research as a means to identify the problem, implement the tool, conduct testing and evaluate the outcomes. As a result, it is evident that system dynamics has the potential to improve the understanding of project interdependencies as highlighted through the investigation of the RAN submarine project portfolio. This will allow the RAN to potentially use the results obtained from the system dynamics tool to improve strategic decision-making processes. In turn, this could enhance the organisational outcomes, such as return on investment in the future.

In conclusion, this research indicates that SD modelling could be a valuable tool for the management of project portfolios. The benefits of SD modelling could extend to other organisations and regions beyond the case investigated, however it is important to understand that further research is required to examine the use of system dynamics as a tool for PPM globally. It is recommended that further research be conducted to apply system dynamics across various industry project portfolios in order to compare results and investigate the possible implementation of results.

References.

1. Kendall, G.I. (2003) *Advanced Project Portfolio Management and the PMO multiplying ROI at warp speed*, J. Ross, Conyers, GA, pg 208.

2. Ghasemzadeh, F., Archer, N., Archer, F., (1999) An Integrated Framework for Project Portfolio Selection, *Project Portfolio Management,* Lowell Dye and James Pennypacker (eds.), Westchester, PA: Centre for Business Practices, pp97-116.

3. Cleland, D. I. (1999) The Strategic Context of Projects. In Dye, L. D.

4. Edwards, M. & Crocker, M. (2001) Major trends and issues, innovation and productivity in services. *Industry, Services & Trade, OECD publications service,* 33, 7-16.

5. Galende, J. (2006) Analysis of technological innovation from business economics and management *Technovation,* 26, 300-311.

6. Cooper, R. G., Edgett, S. J. & Kleinschmidt, E. J. (2001) *Portfolio management for new products,* Cambridge, Mass., Perseus.

7. Levine, H. A. (2005) *Project portfolio management: a practical guide to selecting projects, managing portfolios, and maximizing benefits,* San Francisco, Calif. Chichester, Jossey-Bass ; John Wiley distributor.

8. Soderlund J. (2004) On the broadening scope of the research on projects: a review and a model for analysis. *International Journal of Project Management,* 22, 655-667.

9. Platje, A., Seidel, H. & Wadman, S. (1994) Project and portfolio planning cycle : Project-based management for the multiproject challenge. *International Journal of Project Management,* 12, 100-106.

10. Archer, N. P. & Ghasemzadeh, F. (1999) An integrated framework for project portfolio selection. *International Journal of Project Management*, 17, pp 207-216.

11. Carlsson, C, Fuller, R, Heikkila, M, Majlender, P. (2007) A Fuzzy Approach to R&D project portfolio selection, Science Direct, *International Journal of Approximate Reasoning*, 44, 93-105.

12. Webb, A. (1994) *Managing innovative projects*, London; New York, Chapman & Hall.

13. Zapata, J.C, Varma, V.A, Reklaitis, G.V. (2007) Impact of Tactical and operational policies in selection of new product portfolio, Science Direct, *Computers and Chemical Engineering*, 32, 307-319.

14. Srijariya, W., Riewpaiboon, A., Chaikledkaew, U., (2008), *System Dynamic Modelling: An Alternative Method for Budgeting*, Journal of Value in Health, Vol 11, Supplement 1, pp 115-123.

15. Sterman, J.D., (2000), Business Dynamics: Systems Thinking and Modelling for a Complex World, McGraw Hills Company Inc, USA.

16. Papageorgiou, G., (2010), *Toward a System Dynamics modelling framework for effective political organisation management strategies,* Journal of Political Marketing, 9:1, pp 55-72.

17. Maani, K.E., 2004, Systems Thinking, System Dynamics, Managing Change and Complexity, Pearson Education, New Zealand

18. Snabe, B (2007) The usage of system dynamics in organizational interventions a participative modelling approach supporting change management efforts,Wiesbaden: Dt. Univ.-Verl.

19. Forrester, J., W, (1992) *System Dynamics, Systems Thinking and Soft OR,* Massachusetts Institute of Technology, Cambridge MA 02139 USA, August 18.

20. Royal Australian Navy, (2008), *Directive by the Chief of Navy to Rear Admiral R.C. Moffitt AO, RAN: Submarine Workforce Sustainability Review,* Chief of Navy, Russell Offices, Canberra, http://www.navy.gov.au/Publication:Submarine_Workforce_Sustainability_Review, accessed 02 Nov 2009.

21. ISEE Systems, (2010), *Stella: Systems Thinking for Education and Research*,http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx, accessed 05 Oct 2009.

22. McLucas, A.C., 2005, System Dynamics Applications: A Modular Approach to Modelling Complex World Behaviour, Argos Press, Canberra, Australia.

23. Waring, A., 1996, Practical Systems Thinking, International Thomson Business Press, London, UK

24. Coyle, R.J. (1996) *System Dynamics Modelling: A Practical Approach,* Chapman & Hall, London UK

25. Georgiadis, P., Dimitrios, V., Eleftherios, I., (2004), *A System Dynamics modelling framework for the strategic supply chain management of food chains,* Journal of Food Engineering, Vol 70, pp 351-364.