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Towards a Taxonomy of System Dynamics Models of Higher Education

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Abstract
A number of papers have been published on various System Dynamics (SD) Models of Higher Education Institutions, on topics including the role of SD in Corporate Governance, Planning, Resourcing & Budgeting, Teaching Quality, Teaching Practice, Microworlds and Enrolment Demand. An international seminar on "Using System Dynamics as a Tool for Decision Making in Higher Education Management" was held in June 1999 at the Royal Society, London and South Bank University.

The paper contends that there is a need to catalogue and classify this work in order to highlight potential areas of research in this field of study and to identify system archetypes at different hierarchical levels and discover new ones. This paper therefore presents an initial Taxonomy of System Dynamics Models in Higher Education.

The initial Taxonomy is based on a limited survey of completed SD investigations in higher education management. The findings from these investigations are briefly described. The taxonomy classifies the completed investigations into six specific areas of concern and five hierarchical levels.

1. Introduction

The objective of this paper is to facilitate and structure debate on the use of system dynamics (SD) (Forrester 1961) for higher education (HE) management. Universities are continually evolving to meet government, employer and student needs, hence the emergence of new management problems. To guide management decision making statistical linear models and spreadsheets are widely utilised. We contend (Kennedy and Clare, 1999) that these essentially static modelling approaches are inadequate for this application domain because universities are dynamic, complex, non-linear systems. Such a system can be characterised by interactions of closed chains (or feedback loops) that, when combined, define the structure of the system and hence how it behaves over time. I therefore believe SD to be an appropriate modelling technique for higher education management. A number of SD practitioners have addressed some of the problems of higher education management and the findings from their investigations are outlined in section 3 below. The increased interest in this field is indicated by the holding on an international seminar on 'Using System Dynamics as a Tool for Decision Making in Higher Education Management' in June 1999 at the Royal Society, London and South Bank University, under the auspices of the Society for Research into Higher Education

(Kennedy, 2000). Finally, I present in section 5 below some future suggested areas of research for SD in higher education management.

2. An initial Taxonomy of System Dynamics Models in Higher Education

The initial Taxonomy is based on a limited survey of completed SD investigations in higher education management. The findings from these investigations are briefly described in section 3 below. In light of our limited survey, I believe there is a need to catalogue and classify this work. I present an initial attempt at this below in order to highlight future areas of research in this field of study and to identify system archetypes developed at different hierarchical levels. The completed investigations are classified into six specific areas of concern (Corporate Governance, Planning, Resourcing & Budgeting, Teaching Quality, Teaching Practice, Microworlds, Enrolment Demand) and five hierarchical levels (National, Regional/ State, University/ Institute, Faculty, School/ Department). Some work spans more than one category.

		Hierarchical Level				
		National	**Regional**	**University**	**Faculty**	**School**
	Corporate Governance			Saeed (1996) Saeed (1998 Kennedy and Clare (1999))		
	Planning, Resourcing & Budgeting	Galbraith (1982) Galbraith and Carss (1989) Bell *et al* (2000)	Frances (1995, 2000)	Galbraith (1989, 1998a, 1998b, 1998c) Barlas and Diker (1996) Kennedy and Clare (1999)	Kennedy and Clare (1999)	Kennedy and Clare (1999)
Specific Area of Concern	**Teaching Quality**					Kennedy (1998a) Kennedy (1998b)
	Teaching Practice			Frances (2000)		Roberts (1978) Saeed (1990) Saeed (1993) Saeed (1997) Frances (2000)
	Microworlds			Barlas and Diker (1996)		
	Enrolment Demand		Jordan (1992) Frances *et al* (1994) Frances (2000)	Frances *et al* (1994) Frances (2000)		

Table 1: Preliminary classification of SD work in Higher Education Management

3. System Dynamists' Work in Higher Education Management

A number of system dynamicists have examined some of the problems with the higher education management domain. I shall briefly describe a selection of completed investigations and key findings.

3.1 Corporate Governance

Saeed (1996, 1998)

Khalid Saeed (1996) investigates the dynamics of collegial systems in the context of developing countries. He states that collegial organisations consist of groups of professionals creating intangible products or services. A university is a typical example of a collegial system. While Saeed states that the model is applicable to many of the academic and research organisations established in the developing countries, in my opinion much of the analysis is transferable to other economies. From his analysis he suggests that: "*an unadjudicated collegial system is not sustainable, for it will tend to create an authoritarian administration which will impair the collegial norms and misallocate scarce resources to the activities fueling bureaucratisation and expansion of administrative scope, while professional autonomy. innovativeness and self-actualised behaviour are suppressed. Professional conduct tends to he more value rational than the bureaucracy, since it is subject to reviews by external peers. Thus, legitimisation of referent power is essential to creating value-rational decisions that assure a balanced resource allocation that sustains a collegial system. Limiting scope of the administration through an external scrutiny of its conduct or a charter appears to facilitate this process*".

Saeed (1998) considers the rather wider topic of "Maintaining professional competence in innovation organisations", but this paper is also relevant to HE management.

Kennedy and Clare (1999)

Kennedy and Clare (1999) examine the debate between the "managerialists", favouring strong central direction and the "collegiumists", who see the university as a community of scholars. They also identify the HE Stakeholders & Customers. They argue that the stakeholders of a university fall into four distinct groups (Clare, 1995).

Firstly, the students of the institution are stakeholders (as well as its product). They look to the institution to provide a service in the form of a course of study leading to a recognised qualification and a general educational benefit.

The second category of stakeholders is the employers of graduates and diplomates. Their needs for well-qualified, well-educated and adaptable employees in the shape of new graduates have to be satisfied. Success in this area reaps other benefits such as investment by employers in research, development, consultancy and short courses with the institution. Here, a careful balance needs to be struck between theoretical research and the needs of industry.

The third group of stakeholders is the Government (via the funding councils), local Government and Government agencies (the Research Councils, Training and Enterprise Councils etc.). For the foreseeable future, these bodies will be the major providers of funds to a university. Consequently, they should be regarded as stakeholders with needs to be satisfied. The main way in which this is currently achieved is by the institutions recruiting to target, graduating quality students, completing the funded research and so on.
The final group of stakeholders for the services of a higher education institute is the wider community. Each institution has obligations (although it may not have realised them) in the areas of:

(i) access to the facilities of the institution for the local community
(ii) contribution to the wider academic community

(iii) providing services to the international community via the enrolment of overseas students, collaborative research, consultancy and other projects
(iv) the welfare of society in general.

3.2 Planning, Resourcing & Budgeting

Galbraith (1982, 1989, 1998a, 1998a, 1998a) (Galbraith and Carss, 1989)
Peter Galbraith in an extended series of papers (Galbraith (1982, 1989, 1998a, 1998a, 1998a) (Galbraith and Carss, 1989) has investigated the impact of managerial policy on HE institutional performance, with particular emphasis on time delays between policy change and the results being evident and has posed the question "Are Universities Learning Organisations?"

Galbraith (1998a, 1998b) has identified many positive and negative loops in Queensland University. An example of a positive loop is the process by which an increase in enrolments provides additional resources, which supports an increase in academic staff, which provides for the enrolment of more students, which produce additional resources and so on. An example of a negative loop is the process by which an increase in staff increases the salary bill, which reduces resources available to employ staff, which reduces the rate at which new staff can be appointed, which leads to a reduction in staff etc. In both of these two loops, delays of the order of years are involved before the loops are closed. The structure of complex systems ensures that they are inherently difficult to manage. As Forrester (1994) confirms:

> *"A problem is perceived, an action proposed, a result is expected but the result does not often occur. Symptom, action, and solution are not isolated in a linear cause-to-effect relationship, but exist in a nest of interlocking structures."*

Galbraith argues that recent pressure on the administration of Australian universities is due to government interventions, which has created tensions between the achievement of academic and fiscal goals. He has constructed a SD model to simulate competition between different schools that belong to a faculty that has limited funds. A wide range of employed and postulated policies are investigated. He demonstrates cyclic behaviour is endemic within the current climate despite the intention of managers to achieve stability. Finally, the results of the policy analysis are embedded within a wider discussion of the climate of institutional management, in which the concepts of "corporation" and "ecology" are employed as contrasting metaphors.

Key Findings
• Behavioural outcomes for a university, as for any complex system, are determined primarily by the combination of multiple interacting feedback loops that are a consequence of structural arrangements. The delays and non-linearities in the loops mean that behaviour cannot be predicted easily.
• Strategic plans serve a variety of purposes. For example, within teaching and learning contexts plans to improve teaching methods and to make assessment procedures more accountable are demonstrably worthwhile. Their impacts on university practices are direct, and the image of the institution indirect as public perceptions of changes in quality accrue over time.

• The production of separate plans for faculties, departments and schools means that pursuit of individual targets can in fact undermine the attainment of general institutional goals. If every unit succeeds with an ideal of achieving student growth in a situation where total funding is limited then some units must loose. Galbraith sees this as a version of the 'tragedy of the commons' because there exists a 'commons' or a limited resource shared amongst a group of competing units and the units dictate their own actions in order to maximise their own gains from the common resource. The common resource becomes less productive per individual demand as units work harder for less and less.

• It is argued that the culture of institutional administration, to the extent that it limits its vision to a corporate identify, lags a metaphor behind the world at large. While the world at large, including corporate interests, is moving its thinking beyond self-interested practices, to consider issues such as global warming, the replenishment of forests, and the protection of endangered species, institutional management remains locked in a competitive corporate prison. As Senge (1990) reminds us "*Few large corporations live even half as long as a person*".

As we point out in Bell *et al* (2000), although Galbraith demonstrates the usefulness of the SD technique for HE planning through highlighting its explanatory strengths, he did not work with any key decision-makers at Queensland University. This is a significant limitation of his research, because the findings, though interesting, so far have had little impact on the planning of the university. We contend it is important to work with stakeholders in order to identify the relevant problems. Moreover, model ownership must be achieved through passing verification and validation tests to the satisfaction of the stakeholders.

Barlas and Diker (1996)

The main objective of their research was to construct an interactive dynamic simulation model. The model examines a range of problems such as student growth, faculty ratios, poor teaching quality and low research productivity.

Key Findings

• Simulation experiments with graduate versus under-graduate study orientation has considerable positive effect on research output.

• If, when faced with increased enrolments, we try to keep small class sizes, this implies having multiple sections (or many elective courses) in order to satisfy the class-hour needs of the students. This in turn would mean increased teaching loads for faculty, which would make it difficult to maintain the faculty body (increased quit rates) and the potential faculty application pool ("supply") would shrink.

Kennedy and Clare (1999)

Kennedy and Clare (1999) discusses the factors that should be incorporated in a system dynamics (SD) model designed to assist in policy analysis regarding resource management issues. In a brief survey of current higher education approaches to planning they examine the problems with current methods. They argue that the problem with most input /output models are that they adopt a static, linear view. Such models thus ignore both dynamic interactions between the input /output factors and the nature of the 'transformation' taking place and are thus of little use when considering process improvement. They also examine problems in the utilisation of spreadsheets and the influence of quality/performance measures and indicators on funding.

Bell et al (2000)
Bell et al (2000) categorises their updated Holon Methodology, as a 'soft teleological approach'**.** They state that the underlying principle of the Holon Planning and Costing Framework is: "*To identify an agreed future and to design ways of bringing it about within cost constraints*"

The Holon Planning and Costing Framework combines a soft methodology (Holon) and a hard technique (SD). The Holon Methodology addresses 'the who', 'the what', 'the where' and 'the when' type questions at the current state S_0, and generates a vision of a desired state S_1. Additionally, this produces a relevant metrics programme, and the collected metrics can be used as dynamic behaviour patterns. The explanatory capability of SD tackles 'the how' and 'the why' type questions. Table 2 illustrates the most important traits of this framework.

1	An holistic view of a situation.
2	The use of a soft methodology to enable the capture of the stakeholders' point of view.
3	Controlling the effects of bounded rationality.
4	The researchers' role as facilitator.
5	Development of a desirable and feasible vision.
6	Creation of a relevant metrics programme.
7	Emphasis on the SD model ownership problem.
8	Producing the 'best solution' to achieve the vision given the cost constraints.
9	The continuous use of an SD model for examining various 'what-if' scenarios.

Table 2: Key traits of the Holon Planning and Costing Framework

They report that the Holon Planning and Costing Framework is being applied within SCISM at South Bank University in an exploratory case study. They have conducted a review of QAA and the RAE literature to assist in the identification and labelling of the relevant holons, i.e. 'the where'. We have identified relevant academic and administrative staff, i.e. 'the who', participants in the planning process. Individual and group meetings have been held to identify the problems, i.e. 'the whats', associated with the current state S_0 of SCISM. This has led to the formulation of an agreed desired state S_1, i.e. the vision and an appropriate metrics programme.

They conclude that soft methodologies complement hard techniques, because they examine different types of questions and they contend that representational measurement theory (Fenton, 1991) cements soft and hard systems thinking. They claim that this alternative planning approach should assist in improving teaching and research quality given the cost constraints for it aims to empower the stakeholders.

Frances et al (Jordan (1992), Frances et al (1994), Frances (2000)
See under 3.6 'Enrolment Demand'.

3.3 Teaching Quality

Kennedy (1998a, 1998b)

The information management and modelling research group (IMMaGe) have developed an initial SD model to examine quality management issues facing the school of Computing, Information Systems and Mathematics (SCISM) at South Bank University. Interviews were conducted with academic members of staff to guide the construction of the model. This investigation is considered to be the first part of a long-term project.

Key Findings

• The identification of sectors, *e.g.* Administration, Staff Performance, Department Effectiveness, Funding, Research and Funding, needed to be considered for a future quality management model.

• The identification of metrics (or performance indicators) needed to be collected for further SD investigations.

3.4 Teaching Practice

Roberts (1978)

Roberts (1978) examines student performance in the elementary classroom.

Saeed (1990, 1993, 1997)

Saeed in a series of papers has investigated the role of System Dynamics in developing teaching practice in a number of academic disciplines, including social sciences generally (Saeed, 1990), economic development (Saeed, 1993) and for a "New Liberal Education" (Saeed, 1997).

In these papers Saeed points out that (unlike the teaching of engineering and physical sciences and many of the fine arts), experimental learning is rarely incorporated into the teaching of social sciences. He asserts that this is unfortunate "*since experimentation with relationships, whether in a laboratory or a studio, helps not only to corroborate theories and create robust designs, but also to develop the reflective process critical to the creation of innovation in various professions*" and shows how SD is suited to experimentation with relationships (Saeed, 1990). In relation to teaching practice for "New Liberal Education" (Saeed, 1997), he examines how Kolb's model of experiential learning can be implemented through the use of System Dynamics as a Technology.

Frances (2000)

In this paper Carol Frances introduces the important topic of assessing the impact of new educational technology.

3.5 Microworlds

Barlas and Diker (1996)

The main objective of Barlas and Diker's (1996) research was to construct an interactive dynamic simulation model, on which a range of problems concerning the academic aspects of a university management system can be analysed and certain policies for overcoming these problems can be tested in a "Microworld" format. More specifically, the model focuses on long-term, strategic university problems that are dynamic and persistent in nature, such as growing student-faculty ratios, poor teaching quality, and low research productivity. The model generates numerous performance measures about the three fundamental activities of a university, namely, teaching, research and professional projects.

3.6 Enrolment Demand

Frances et al (Jordan (1992), Frances et al (1994), Frances (2000)
Carol Frances and co-workers [Jordan (1992), Frances *et al* (1994), Frances (2000)] have reported on several interventions by constructing system dynamics models to improve planning and budgeting for higher education, both to inform public policy /State Management [Results from Arizona], and to inform university wide policy [Results from Houston, Texas]. She has also reflected on wider issues in other papers (Frances, 1995).

A SD model was constructed for the Arizona Board of Regents. The model was used to examine student enrolment demand over a period of 20 years. Further modelling work was conducted with the University of Houston System investigating strategies for generating new enrolment demands amongst Houston's Hispanics and African American populations.

Key Findings
• If a system is on a slow-growth path, it may be very difficult to alter the course of that path, but SD can help identify the areas where policy or management changes have the potential of being most effective in producing desired results. Additionally, counter-intuitive patterns are frequently discovered. Multiple sub-systems interact over time to generate results that are often beyond the causal observers' ability to project.
• Another insight gained from the sensitivity analysis using the models is that when wrong decisions are made and, for instance, the financial situation of an institution deteriorates, reversing the decisions does not immediately restore the previous financial conditions. These findings accord with those of Galbraith.

3.7 Other Higher Education Contributions
Radzicki, Winch and Boucher have developed SD models in higher education management and (at present) this proprietary work remains unpublished. However, Winch and Boucher hope to publish materials based on their work for Higher Education Funding Council for England (HEFCE) in due course

4. Why System Dynamics
In our previous work (Kennedy and Clare, 1999) we have suggested that the potential combination of SD to IS/IT HE management appears to lie in three areas:

Firstly, at the most basic level, in some cases it may be possible to replicate existing models developed originally using other modelling styles or techniques. In this domain this is normally spreadsheets. The author has described various replications of this sort (Kennedy, 1997(a), Kennedy, 1997(b)). This process may be of value in convincing managers that they are not losing desirable aspects of their current systems, in better handling any dynamic behaviour incorporated in the previous model, in building confidence in SD models and in giving some secondary benefits such as better documentation, but it will not generally realise the full potential of SD. In some cases, it may allow for the incorporation of other factors (e.g. intangible benefits) that were not incorporated before, or any dynamic behaviour known of but not previously incorporated, in an enhanced model. It could also form the basis for a more radical reconstruction incorporating tried and tested elements of the previous [non-SD] model.

Secondly, it is possible to produce SD models of some of the issues mentioned in this paper. Some examples are discussed above. The requirements for such a model need to be identified and analysed effectively, particularly as requirements change over time, as management changes its decision styles, and staff need new operational data and information. Delays between action and result are of particular importance.

Thirdly, we may develop models showing HE management processes before and after a proposed process change. The anticipated value of the benefits derived, (in terms of greater revenues, resources saved or perceived improvements in quality or reputation), can be compared to the estimated costs. This would be of considerable value in "Transformation" type projects. At present assessing the impact of new educational technology is of particular importance (Frances, 2000).

5. Conclusion

Based on the discussion above and our previous published work I would propose the following research themes:

5.1 Higher Education Planning: Where Next?

The objective would be to examine the theoretical justification for HE planning approaches and tools. It would contain a review of current higher education approaches to planning including input/output models, regression models, spreadsheets and compare the potential of SD. It would also highlight the meta-theoretical assumptions underpinning these planning approaches

5.2 A Critical Review of System Dynamics Models that Investigate Higher Education Issues

The objective would be to identify relevant SD structures for incorporation in future work, to examine the appropriateness of different styles of SD modelling in this area, so guiding the selection of an appropriate research approach. It would describe the key findings of previous research papers and outline their underpinning research approach.

5.3 Highlighting Important Higher Education Management Issues

The objective would firstly be to identify "The Givens" in Higher Education e.g. in the UK the Research Assessment Exercise [RAE]. It would then examine the various conjectures on the way that "The Givens" influence the structure of higher education systems and policy formulation

5.4 Assessing the Impact of New Educational Technology

6. Summary

The potential value of SD for HE management is in incorporating non-linear and iterative views, hard and soft issues, strategic objectives, and changes in educational processes. A SD model of a HE institution should help management to investigate the impact of specific policies before implementing them. This paper shows the potential role of SD in coping with the ever-reducing resources available and increasing quality standards demanded of higher education institutions in many parts of the world.

It is emphasised that this review is reported as the early stage of a long-term project. The authors would welcome comments from these with an interest in the field, particularly those interested in some form of continuing dialogue or collaboration.

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