9

Modelling of Education Systems in Africa for Performance Assessment and Improvement

Prof. R.K. Appiah
Director, CAL Project,
University of Zimbabwe

ABSTRACT

The first step in assessing the performance of a complex dynamical system is to identify a set of significant quantities and attributes to measure. And a good understanding of such systems, obtained from modelling and simulation, is a pre-requisite for this identification. This paper outlines two block diagram models of engineering education systems in Africa for use as tools for thought towards enhancing understanding of such systems.

Keywords: Engineering education, model, system dynamics

INTRODUCTION

The present World Bank initiative on how to assess engineering education and training in Africa is intended to lead to the improvement of engineering education and training in Africa. The World Bank has made clear their disillusionment with the performance of various sectors of the economies of Africa [1], including education [2]. This indicates clearly that the African economies have not behaved as the World Bank had expected them to.

But such counter-intuitive behaviour is characteristic of complex dynamical systems, which African economies are, and indicates that a better understanding of the systems is called for. The best way to understand such systems is by modelling them. In fact, as C.H. Waddington puts it [3]:

> "Investigating just why complex systems do not behave as expected is the main purpose of trying to make models of them."

The purpose of this paper is to outline, in broad terms, two simple models of engineering education systems in Africa which may be found useful as tools for thought towards a better understanding of the behaviour of these systems.

Discourse in the soft sciences tends to use verbal modelling most of the time. This is in spite of the fact that in many such discourses even the simplest graphical model would help to clarify the interactions among the variables and subsystems being discussed. Although the power of graphical models has been realized in these sciences and one finds the use of, say, influence diagrams, etc., graphical models are still not widely used. This contrasts sharply with engineering and the hard sciences where graphical and mathematical models are the order of the day. In engineering, block diagrams are the most favoured representations, particularly in systems and control engineering.

In this paper we present block diagram models of an (engineering) education system (EES). The models help to identify a set of processes and significant variables and their attributes that ought to be studied in performance assessment and improvement exercises. They also throw up questions whose answers should lead to a better understanding of the EES.

Section 2 of the paper presents the development of the models, and in section 3 the significant system variables and their attributes are identified and listed in a measurement schedule. Policy and system dynamics are discussed in section 4 and illustrated with an aspect of quantitative assessment of the University of Zimbabwe's Faculty of Engineering. The uses of the models are further discussed in section 5. Conclusions are drawn in section 6.

Note, the models presented here are by no means complete. They are intended to stimulate and clarify discussion, and be a subject of discussion, refinement and extension.

THE MODELS

The modelling exercise begins with the realization that the EES is an "open" socio-economic system situated in an environment - the system interacts with its environment across

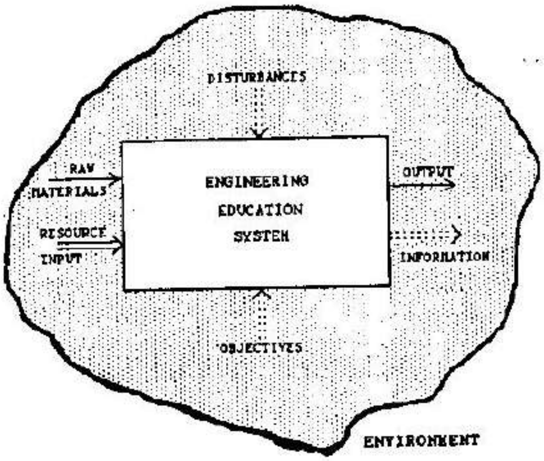

Fig.1:Education System/Environment Interaction.

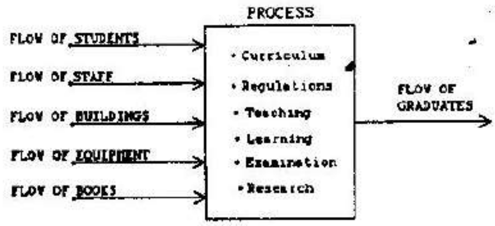

Fig.2: Resource-Flow Diagram.

the system boundary. This situation is captured in Fig. 1. The environment influences the system through the provision of: (a) raw materials, (b) resources, (c) objectives, and (d) disturbances. The system then outputs processed resources and information about its performance into the environment.

Next, the EES, as a managed socio-economic system, is perceived as comprising two main sub-systems, namely: (a) a resource flow sub-system, and (b) an information sub-system. Fig.2 shows the basic resource-flow diagram. In it we have a collection of processes:

- Curriculum,
- Regulations,
- Teaching,
- Learning,
- Examination, and
- Research

They are lumped together in a block labelled "Process." It has as its inputs: (a) the flow of raw materials, i.e. student intake, and (b) flows of resources, namely, staff, buildings, equipment, and books. The output of the process is the flow of (engineering) graduates.

But the process employs stocks of resources, not their flows. Consequently, in Fig.3, integrators are introduced in the resource flow paths in order to accumulate the resources. Also, since the stocks of resources do depreciate, then, this must be accounted for by showing resource depreciation rates. (By stock depreciation we mean, for example, that staff do resign, retire, die, or get sacked; and equipment does age, break down, get stolen, etc.)

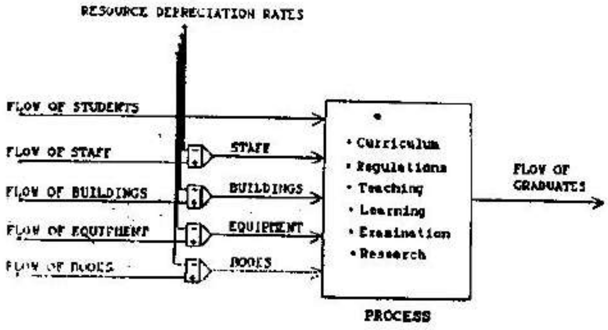

Fig.3: Modified Resource-Flow Diagram.

Superimposed on this resource-flow sub-system is the information (or management) sub-system. Information gathered about the system output is fed into the management sub-system. In this exercise we elect to measure the flow rate of the output stream (here designated as "quantity", with a slight abuse of language), its quality, and the relevance of its acquired knowledge and skills. Most importantly, the management sub-system must also receive the *objectives* of the overall system from its environment. For, the performance of the EES can only be properly assessed against the objectives as set by the designers of the system.

Using the set objectives and the feedback information the management sub-system generates, hopefully, rational policy decisions whose implementation:

1. regulates the flow of resources and raw materials to the process, and
2. alters the process itself.

Superimposing the information sub-system on the resource-flow sub-system results in the overall model of the EES as shown in Fig.4. This model is recognized as a *self-adaptive feedback control system model* specifically because management does manipulate the educational processes, as obtains in some African countries, we end up with the plain *feedback control system model,* without self-adaptation (Fig.6).

The structure in Fig. 6 has been extensively studied in systems and control engineering, biology, and elsewhere. Certain basic properties of the structure are known, and these properties remain the same whether the system is

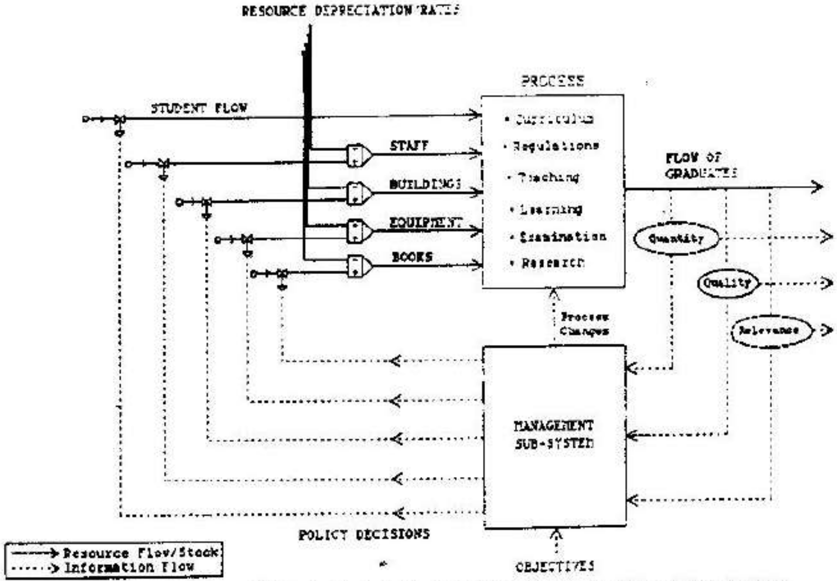

Fig.4: Closed-Loop Feedback System Model of Engineering Education System.

technological, biological, economic, or what have you. For example, positive feedback will produce growth, and negative feedback which regulate a system output variable to a desired value.

The self-adaptive structure in Fig. 5 has been identified in various fields of study but has not been as extensively studied as the previous structure. Perhaps this is because they do not occur in engineering where process changes are environmentally caused - process controllers and operators cannot change the process.

OBJECTIVES, VARIABLES AND ATTRIBUTES

It is more important first to identify the set of quantities and attributes to measure in order to assess the performance of an EES than to seek to answer the technical question: 'How do you measure this or that?' The measurement set must, of course be sufficiently rich in interaction and be represented in the objectives that were set for the system. Therefore, it is important to know what these objectives were so as not to judge the performance of the system against some arbitrary objectives. The objectives themselves ought to be scrutinized to see whether they were achievable in the first place, given the initial conditions of the system, feasible resource flows, and external disturbances.

The position taken in this paper is that all this must be done from the perspective of a good understanding of the behaviour of the system. And, further, that such understanding can come from modelling the system.

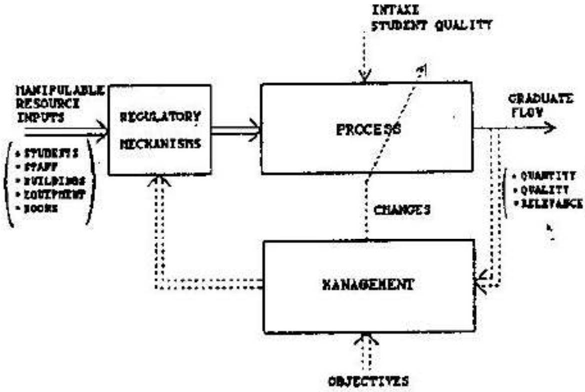

Fig.5: Self-Adaptive Feedback Control System Model of Engineering Education System.

Table 1: Measurement Schedules

ITEM	VARIABLE/ PROCESS	ATTRIBUTES		
		QUANTITY	QUALITY	RELEVANCE/ EQUITY
1	Student Intake	x	x	
2	Staff	x	x	
3	Building	x	x	
4	Equipment	x	x	
5	Books	x	x	
6	Curriculum			x
7	Regulations			x
8	Teaching	x	x	
9	Learning	x	x	
10	Examination		x	x
11	Research	x	x	
12	Graduate Flow	x	x	x
13	Management		x	
14	System Objectives			x

From the model in Fig. 4, we offer a measurement schedule in Table 1 which lists the processes and variables, together with their attributes, to be measured for a first shot at performance assessment. For a start, 25 measurements are proposed. Further refinement and extension of the model will naturally lead to a refinement of the measurement set.

Management (or policy) is included in Table 1 and calls for discussion. This is taken up in the next section.

POLICY AND SYSTEM DYNAMICS

By the dynamics of the process, we mean how staff, buildings, equipment, books, curriculum, regulations, examinations, teaching, learning, and research interact to turn a student into a graduate. This is a complex dynamic interaction.

But it is in the nature of socio-economic systems that the dynamics of the process cannot be studied in open loop, without the policies in the management sub-system. The management sub-system has to be in place with its policy or policies operative and it is the dynamics of the system (Fig 5 or 6) as a whole that have to be studied [4]. But it is a fact of life that policies do change. Consequently, to understand why the system behaved the way it did requires knowledge of the policies that were operative. (This is in contrast to engineering systems and it is one reason why managed socio-economic systems are more difficult to understand than engineering systems.) This point is rather important and calls for an illustration.

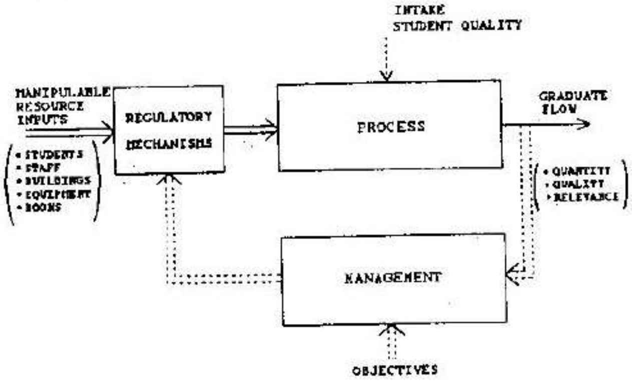

Fig. 6 Feedback Control System Model of Engineering Education System.

ILLUSTRATION

To illustrate the point above consider, as an example, an aspect of a quantitative assessment of the University of Zimbabwe's Faculty of Engineering. Table 2 gives the input-output statistics for the faculty from inception in 1974 to 1991. Fig. 7 shows the non-completion rate. The point we are making is that the dynamic behaviour that these figures exhibit includes the effects of the policies of the various faculty administrative regimes over the years. Whenever policy changed the behaviour of the system also changed. These dynamics cannot be reproduced without knowing what the policies were.

Table 2: Input-Output Figures, Faculty of Engineering University of Zimbabwe

YEAR	INTAKE	GRADUATES	NON-COMPLETION RATE %
1974	16		
1975	52		
1976	31		
1977	28	11	31.3
1978	28	25	51.9
1979	11	18	41.9
1980	68	18	42.9
1981	83	17	39.3
1982	74	9	18.2
1983	68	29	57.4
1984	79	42	33.3
1985	116	52	29.7
1986	135	53	22.1
1987	176	75	5.1
1988	190	91	22.9
1989	179	90	33.3
1990	182	145	17.6
1991	180		

Source University of Zimbabwe

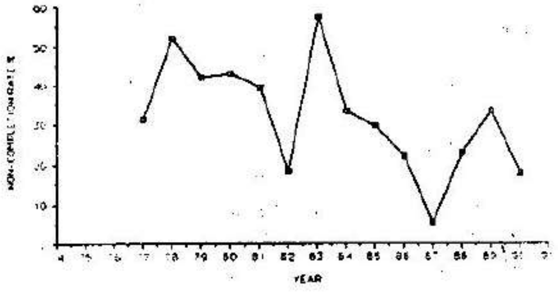

Fig. 7 Non-Completion Rate - Fac of Engineering Univesity of Zimbabwe

But why is this point important? It serves to highlight the crucial role of policy and, therefore, of management in the EES. Consequently, an analysis of the policies operative in the EES must form part of the assessment exercise. And policy design [5] must be given serious attention when it comes to improving engineering education in Africa.

OTHER USES OF MODELS

As mentioned in the introduction, the main purpose of a model of a complex system is to facilitate understanding of the counter-intuitive behaviour of the system. Another purpose of making models is to be able to test strategies for influencing system behaviour in order to find the appropriate strategy or strategies to implement on the real system. All this is done through computer simulation. But our models are not yet parameterized for computer simulation.

However, with even the simple models that we have we can start posing clear and precise questions about the system - questions whose answers will enhance our understanding of the behaviour of the system so that we can design policies in order for it to perform as we expect in the future. Mere inspection of the models prompts some such questions:

1. Is it desirable that management be allowed to manipulate the educational processes or not? In other words, which is better: a system that allows such manipulation (Fig. 5) or the system that disallows it (Fig. 6)? Both systems can be found in Africa!
2. What mechanisms can be employed for effective regulation of student intake, on one hand, and the flows of staff, buildings, equipment and books, on the other hand, in any given environment?
3. Can management do something about the resource depreciation rates? If so, what mechanisms can be employed?
4. What are the effects of time delays within the system? Etc.

Further work on such models will undoubtedly, lead to answers to these and various other scenarios, and consequently, to the design and implementation of improved engineering education systems in Africa.

CONCLUSION

In this short paper it has been argued that modelling will lead to a better understanding of the dynamic behaviour of engineering education systems in Africa. This understanding will in turn lead to the identification of the proper measurement set for performance assessment. It will also lead to better-managed engineering education and training in Africa. Two such simple, highly aggregated models in the making have been offered as tools for thought to provoke and stimulate discussion.

Data for an aspect of quantitative assessment of the Faculty of Engineering, University of Zimbabwe, have also been presented and discussed in the context of the role of policy in the engineering education system.

Clearly, more work requires to be done to refine, extend and simulate these models.

References:

1. *"Sub-Saharan Africa: From Crisis to Sustainable Growth," The World Bank, 1989.*
2. *"Education in Sub-Saharan Africa: Policies for Adjustment, Revitalization and Expansion," The World Bank, 1989.*
3. *C.H. Waddington: "Tools for Thought," Jonathan Cape, 1977.*
4. *R. K. Appiah and R.G. Coyle: "A Modern Control Engineering Approach to System Dynamics," Proc.. Int. System Dynamics Conference, July 1983, Boston, USA, pp 405-449, Plenary Session Paper.*
5. *R.K. Appiah: "A Control Engineering Contribution to Managed Systems Design," ANSTI Seminar on Systems and Industrial Development in Africa, Addis Ababa University, May 1983.*