THE EFFECTS OF ALTERNATIVE POLICIES ON STUDENTS IN ITM : A CASE STUDY IN MODELLING COMPLEX SYSTEMS USING SIGNED DIGRAPHS

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1. Introduction.

Most problems involving society are very complex as they involve many interrelating factors. Quite a number of these factors are hard to identify or quantify because of their subjective nature. Thus in many mathematical models of complex systems there will normally be some degree of imprecision. One way to reduce imprecision is by using signed digraphs to build simple mathematical models of complex problems based upon minimal information.

In this paper we shall use signed digraphs to study the effects of alternative policies on students in ITM. At the same time we will investigate the mathematical interpretation of behavioral science theory pertaining to the sustanance and channelling of motivation by society and organization. We will see that there is a very strong connection between the Expectancy Theory by Lyman Porter and Edward E. Lawler III and the observations made by Maruyama (1963).

It should be noted here that the overall signed digraph for the effects of alternative policies on students in ITM is extremely complex as shown in Figure 5. However, by carefully studying the underlying structural characteristics of the signed digraph and using the theory of graphs we can partition the signed digraph into components. We will study the digraphs component wise and derive the conclusions from there.

2. Standard Definitions.

A directed graph (digraph) $G(V,E)$, consists of a set V of vertices, a set E of edges, and two maps $I: E \rightarrow V$ and $J: E \rightarrow V$, which assign to each edge $e \in E$ an origin $I(e) \in V$ and a destination $J(e) \in V$. The term 'node' is sometimes used instead of vertex, as are the terms 'arc' and 'link' instead of 'edge'.

A signed digraph $S(G,f)$, consists of a digraph G, and a sign function $f: V \rightarrow \pm$. The function f actually assigns to each vertex a + or - sign.

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In modelling a complex system the elements of the vertex set V are variables relevant to or representative of the problem at hand. There is an edge e ∈ E from variable u to variable v , where u , v ∈ V, if a change in u has a significant direct effect on v. We assign a '+' sign to e if the effect is *augmenting* and a '−' sign if the effect is *inhibiting*. By augmenting we mean that all other things being equal, an increase in u leads to an increase in v, and a decrease in u leads to a decrease in v. And, the effect is inhibiting if all other things being equal, an increase in u leads to a decrease in v, and a decrease in u leads to an increase in v.

A *path* from vertex u to w in a digraph is a list of vertices in which successive vertices are connected by an edge in the digraph. For example, uv̂w is a path from u to w in the digraph in Figure 1.
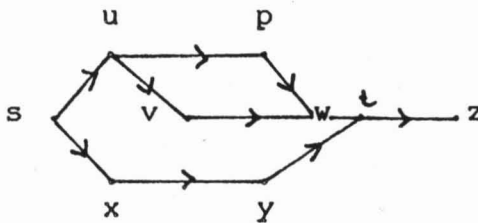

Figure 1.

A *cycle* in a digraph is a *simple path* i.e a path that visits a vertex only once and starts and ends at the same vertex. The term 'simple closed path' is sometimes used instead of 'cycle'. Note: The term 'network' will be used synonymously with 'directed graph'.

In a signed digraph, a cycle is called *deviation-counteracting* if an increase in any variable on the cycle ultimately leads, through the other variables on the cycle, to a decrease in the variable, and vice versa. A cycle is called *deviation-amplifying* if an increase (decrease) in any variable on this cycle ultimately leads to further increase (decrease) in this variable. The term 'positive feedback loops' is sometimes used instead of 'deviation-amplifying cycles' and 'negative feedback loops' instead of 'deviation-counteracting cycles'.

Observation (Maruyama [1963]*)*. A cycle is deviation-amplifying if and only if it has an even number of - signs, and it is deviation-counteracting otherwise.

3. The First Partition Of The Signed Digraph.

The first partition on the signed digraph for the effects of alternative policies on students in ITM is shown in Figure 2 below.
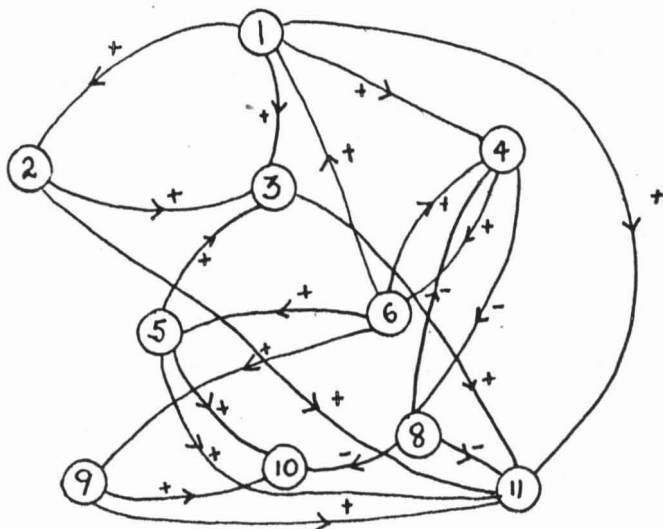

Figure 2. Signed Digraph for the effects of alternative policies on lecturers' performance.

Key:

1	Pay, allowances, and benefits
2	Physical environment
3	Job satisfaction
4	Number of lecturers
5	Facilities provided
6	Budget
8	Contact hours
9	Reference Materials
10	Research and development
11	Lecturers' performance

The signed digraph above describes the important relationships among a number of variables related to lecturers' performance. The edge $(5,3)$ is $+$ because, all other things being equal, an increase in facilities provided leads to an increase in job satisfaction, and conversely a decrease in facilities provided by ITM leads to a decrease in job satisfaction among the lecturers. The edge $(8,10)$ is $-$ because an increase in contact hours of lecturing will reduce the amount of research that can be done by the lecturers. Other signs are determined in a similar manner.

An important factor to notice is the absence of any deviation-amplifying cycles in the signed digraph in Figure 2 that involve variable ⑪ (Lecturers' performance). This indicates that an increase in any variable related directly or indirectly with ⑪ does not ultimately lead to a further increase in lecturers' performance. This is in accordance with Maslow's Hierachy of Human Needs Theory which suggests that once people have achieved satisfaction the incentives become less motivational. Hence there must be other factors that drive them to sustain and/or improve their current performance. We will show that the partition above is strongly related to the second partition of the complete signed digraph.

4.   **The Second Partition Of The Signed Digraph.**

Key:

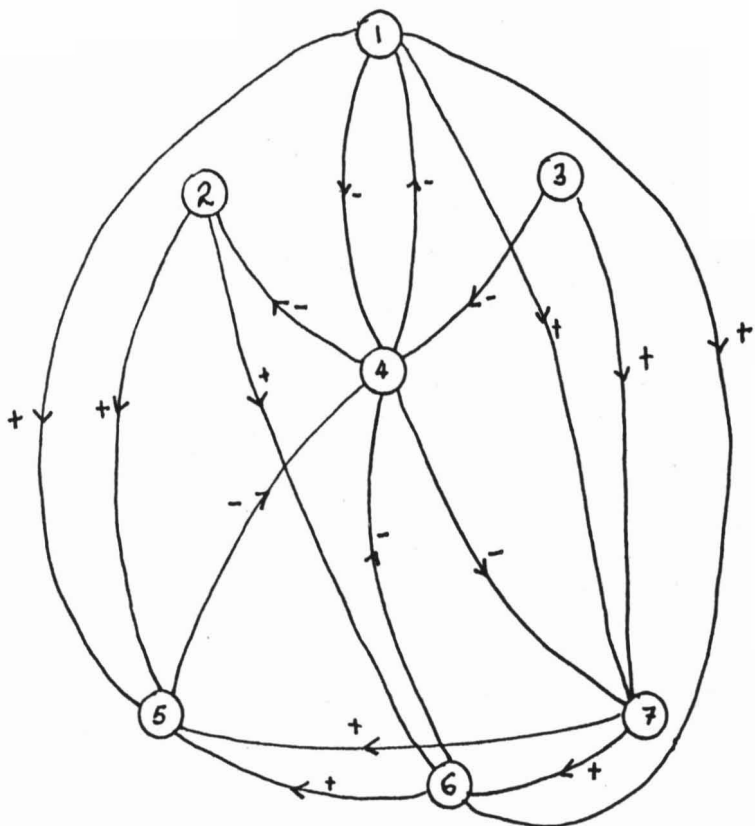|		
1	lecturers' performance	⎫
2	Research and development	⎬ A
3	Students' Facilities	⎪
4	Environmental stress	⎭
5	Public confidence	⎫ B
6	Reputation of the Institution	⎭
7	Students' performance	⎬ C

Figure 3. Signed digraph for the effects of policies on students' performance.

The signed digraph in Figure 3 above describes the important relationships among a number of variables related to students' performance. The seven variables that are connected to each other are actually the elements of three main factors. Variables ① through ④ are the elements of ITM policies in the main digraph in Figure 5. Although variable ① (Lecturers' performance) seems to be out of contact here, we have shown in the first partition of the signed digraph how the alternative policies available do in fact influence the performance of the lecturers. Therefore the inclusion here is quite reasonable as it does provide a clearer view of what we are analyzing.

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Variables (5) and (6) are elements of what we call *outside factors* related strongly to the institution. It was shown by Kruzic (1973) that outside factors such as public confidence has a great influence on the performance of an organization. Finally, variable (7) in this partition represents the important factors relevant to the students in ITM.

Variables (1) , (4) , (7) , (6) and (5) form a cycle which is deviation-amplifying. This suggests that the relationships among the above variables are unstable. In fact, in the second partition most of the cycles are deviation-amplifying, namely cycle { (1) , (6) , (5) , (4) , }, cycle { (2) , (5) , (4) , } and etc. (See Figure 3.). The existence of deviation-amplifying cycles in this partition suggests that, initial changes can be amplified way beyond their immediate effects (Cf. Roberts [1973, p. 188].). The immediate result of this situation from a structural point of view is that an initial decrease in students' performance is amplified in a further decrease in students' performance if we do not introduce changes in the fundamental structure of the network.

If we take a closer look at the cycle formed by variables (4) , (7) and (6) we see that a decrease in students' performance results in a decrease in the reputation of the institution. A decrease in reputation results in more environmental stress, and this will cause a further decrease in students' performance which will also result in a drop in lecturers' performance. At the same time, through cycle (4) , (2) , (5) , increased stress leads to a decrease in research and development among the lecturers which will in turn result in decreased public confidence in the institution. Through variables (5) , (4) and (7) we can see that, indirectly, public confidence also plays an important role in students' performance. This will be discussed further in the next section.

These relationships suggest that it is vital for us to periodically monitor students' performance through the CGPA or other measures commonly used as this will provide relevant information concerning lecturers' performance, public confidence, environmental stress and etc.

5. The Complete Signed Digraph.

Figure 5 shows the complete signed digraph of the effects of alternative policies on the students in ITM. In this figure we have included one big factor influencing the students that has not been analysed before, namely the student size. There are several reasons as to why the student size factor is not included in the previous partitions.

The first reason is that when the authors try to include this variable in the first or second partition, it creates many unsolved arcs, meaning here that we do not know what sign to put on a particular arc. Avoiding unnecessary uncertainty in the model, student size is not included in either partition. The second reason is that student size is such an important factor that it is worth studying on its own. In this complete digraph therefore we can regard student size as a third partition that is strongly connected with the other partitions.

If we were to form a signed digraph of classes of the variables, we would obtain the digraph in Figure 4 below.
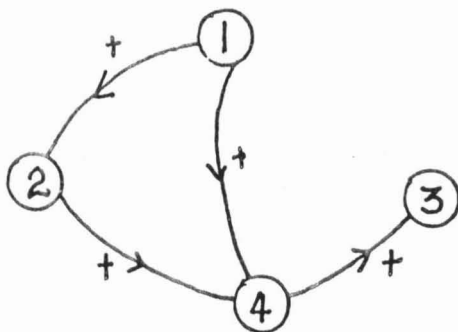

Figure 4. Signed digraph of classes of variables

Key: 1   Lecturers' performance
         2   Student size
         3   Students' performance
         4   Public confidence

From the signed digraph in Figure 4, it is obvious that nothing much can be obtained by merely looking at the classes of variables affecting each other. Nevertheless there seems to be a pure destination as to where the flow of effects is pointing to. If lecturers' performance increases, students' performance will also increase. This in turn leads to more public confidence in the institution. More confidence means people will try their best to send their siblings to ITM, thus increasing the student population in ITM provided the limit (control measure) is not exceeded. What does this mean in terms of academic environment in ITM if the institution is not expanded accordingly? From the detailed signed

digraph in Figure 5, student size does have a great impact not only on students' performance but also on the whole system of ITM.

By looking at cycle AB, AA, SA, CGPA and AL (Refer Figure 5.), which is deviation-amplifying, we know that at least one of the flow processes involving student size is unstable . Although the other cycles involving student size are deviation-counteracting, this does not rule out the possibility that the effects of student size on CGPA, via other cycles, (provided other variables remain constants) can be negative. Unfortunately there is no study being done on this relationship yet.

One big advantage of using signed digraphs is that we can pinpoint with reasonable certainty where to introduce positive or negative 'kicks' (changes). For example if the institution cannot cope with the growing space demand(classrooms, hostels, and etc.), we can always impose a stricter entry requirement as this will have a direct consequence on the student size. (See Figure 5.). If on the other hand we want more research to be done by the lecturers, we can reduce the contact hours per lecturer. A direct consequence of this is that there will be more time for student counselling by the lecturers which will lead to better students' performance.

The cycles formed by variables AJ, AK and AL are deviation-amplifying with definite positiveness. This observation makes precise, from a structural point of view, as to why the research and development department in any institution is very unstable. It suggests that once you are known for R & D advances the public will expect more and more from the institution. The reputation of the institution will then depend greatly on the R & D department. By including variable AF* (contact hours) in the cycle we will see that a further decrease in contact hours is needed for each lecturer. This factor has prompted many western universities to have a separate R & D department with non lecturing professors or to give sabatical leave to researching professors.

6.   Concluding Remarks.

In our signed digraph for the effects of alternative policies on the ITM students we have included only some of the most significant direct relationships. We have avoided introducing arcs with questionable signs due to the complexity of the network. However, a method that has been used widely in resolving this situation is to analyse the questionable arcs under both choices of signs.

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At the time of this writing, deeper analysis is still being done on the digraphs. Any conclusions that can be drawn from the digraphs are still subjected to a sensitivity analysis. The signed digraphs are also being analysed by following the propagation of initial pulses through the system. However, due to the complexity of the system, it is necessary for us to do the sensitivity analysis and the autonomous pulse process on the system using computer softwares that are currently available.

Key:

AA	Environmental stresses
AB	Students size in hostels/rooms
AC	Class size
AD	Students' services
AE	Study conveniences
AF	Contact hours
AG	Consultation hours (lecturers/students)
AH	Reference materials
AI	Library hours
AJ	Reputation of Institution
AK	Academic/research and development
AL	Public confidence in the institution
AM	Practical training
AN	Lecturer's attitude towards subject being taught

Note: Variables beyond students' control (AA through AN)

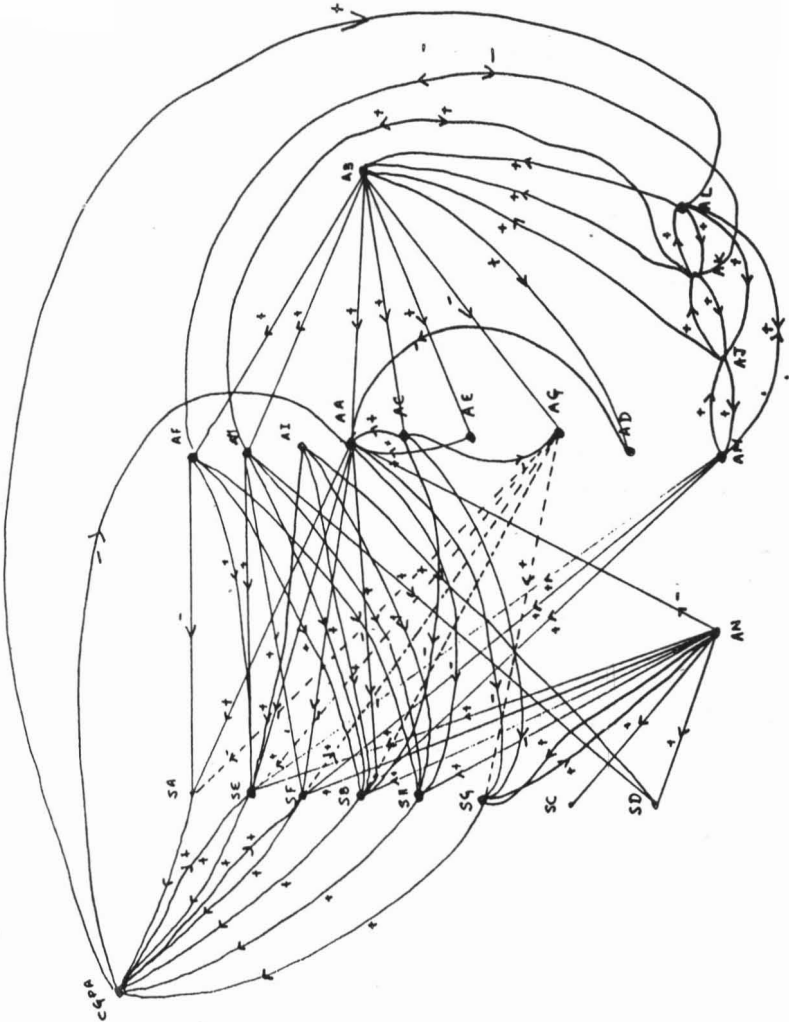|	
SA	Interaction with councellors
SB	Understanding of materials
SC	Extracurricular activities
SD	Extra reading on area of interest
SE	Motivation
SF	Attitude towards studies
SG	Class attendance
SH	Study hours

Figure 5. The complete signed digraph of the effects of alternative policies on the students in ITM.

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