Supply and Demand of Computer Personnel in African Developing Countries — A System Dynamics Model —

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Abstract

In this paper, we propose a system dynamics model to deal with the main factors which influence critically the education and training of computer personnel in African developing countries (ADC). In the model, the needs of industry for skilled computer personnel are determined. According to these needs the required education infrastructure and facilities are provided and the appropriate number of students and professors are planned and educated. Factors like standard of living of the population and resources allocated by the organizations for worker training are taken into account in the model because of the importance of their influence on the results of the education and training system. The model will allow the managers of IT field to design and select the more appropriate policies to match the education and training requirement of the computer personnel in the country.

1 Introduction

The lack of computer specialists (in terms of number and quality) emerges as the most important problem in information technology (IT) development in ADC. In most of these countries the increase of the economic and social activities creates more and more needs for computerization. All kinds of information systems are developed in state administration, private companies, financial institutions, education and research institutions, etc.. But without having recourse to software houses of developed countries, software development projects generally fail. Either the project is not entirely completed or the delivered system does not work as expected originally.

So, local computer personnel must be educated and trained. Also, all the society must be sensitized to the utility and secondary effects of IT on the nation's development process. To perform this education and sensitization a lot of investments must be made. But how many computer students must be educated? When and how much, so far as resources allow it, must be invested in education infrastructure and facilities to best meet the evolving national computerization needs? The employment problems as well as the lack of computer manpower have to be avoided. Also investment must be done proportionally to the needs in order to avoid the unnecessary infrastructure as well as the insufficiency of equipment. Generally these problems are solved by trial and error. This is one of the most important causes of the permanent shortage of skilled computer personnel in these countries.

In this paper, we propose a system dynamics model to face more efficiently these problems. This model serves as a tool for better control of the IT education sector by simulating the relationship between computer personnel, computer students, education infrastructures and facilities. It allows the analysis of various policies, putting out their respective advantages and drawbacks on the effort of matching needs and investment.

2 Structure of the Model

In this section we present the general structure of the model, a simplified causal loop, a dynamo flowchart of education and training sector, the curves and mathematical expressions of the more critical rate equations(graduation, school leaving, and profession leaving rates).

2.1 General Structure

Figure 1 shows the relationship between the three sectors (industry, education and training , and government sectors) of the model. Industry sector includes all the national activities for services and goods production. It expresses its needs for computer personnel to education and training sector. With the resources allocated by government, computer personnel is educated, trained and sent to industry sector.

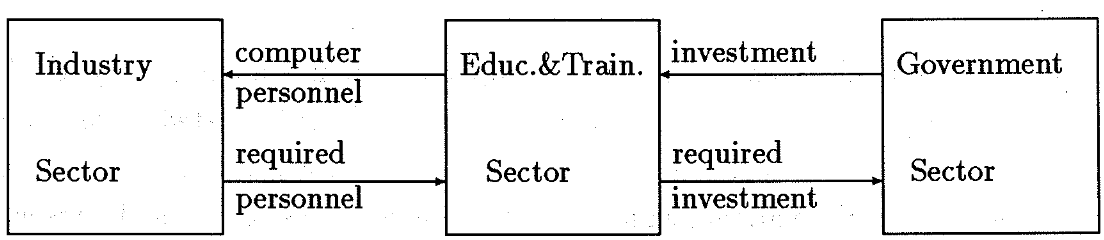


Figure 1 General Structure of the Model

2.2 Simplified Causal Loop

Figure 2 presents a simplified causal loop of the model. In the model, computer personnel is divided into system engineers, programmers, and operators. The education of the lowest level computer personnel like punch operators is not taken into account. Because this personnel is educated and trained generally by computer maker companies which are not under the control of the government. The education under consideration here takes place at higher education institutions.

Needs for computer personnel are registered periodically by government. Every

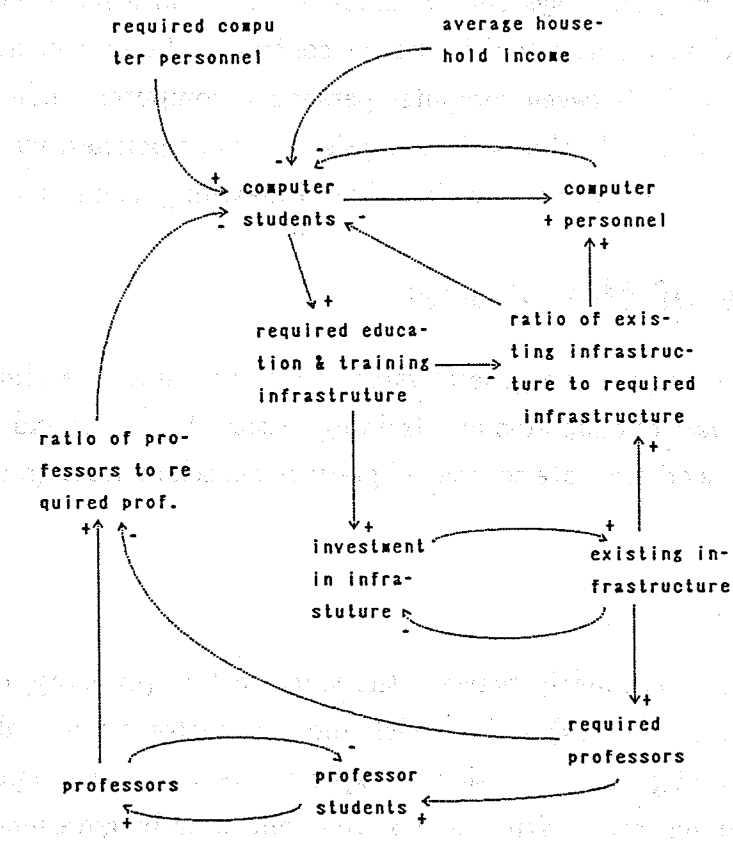


Figure 2 Simplified Causal Loop of the Model

organization is required to report how many computer personnel are necessary for short and middle term goals. And the number of the persons to be educated is determined and planned over years in function of these needs. The reason of this approach is to match the needs and the national education effort. Also in the limits of the resources available for IT education and to keep the quality of the computer personnel at a good level, the number of students per professor is decided at government level. Then, the number of required professors is calculated. And according to this calculated number, students are sent to the education institutions of developed countries for doctor course.

Most ADC have not yet the necessary environment to provide this course. The cumulative education infrastructure is the basic variable which determines the capacity of the country to educate students in IT as well as to train the computer personnel of the industry.

The more the number of computer students grow, the more the needs for infrastructure, facilities, and professors grow. In turn, the more infrastructure, facilities, and professors grows more the number of students decreases (more students graduate every year) and computer personnel grows. The more computer personnel grow in terms of number and quality the more important IT effect becomes on productivity in industry. As a consequence, national production increases, new investments made in industry create new requirement for computerization and computer personnel. And the cycle rebegins.

The quality of the computer personnel is implicitly taken into account in the model. This quality depends on the values of parameters like number of students per professor or cumulative education infrastructure per student.

2.3 Simplified Dynamo Diagram

In figure 3 only the loop of the infrastructure subsector is represented. The principle of its interaction with the student-personnel loop is the same as those of the facilities and professor subsectors. The number of professors and facilities are proportional to the number of students. Infrastructure, facilities and professors subsectors receives investment from government according to their requirements and the IT resource distribution policy. A policy is defined by a set of values of a number of variables such as "fraction of requirement to be invested : FRI" in figure 3. The total required investment of IT education sector is the sum of the required investment of the three subsectors. Each required investment is equal to the gap between the required asset and existing asset. The ratio of existing asset to required asset defines the availability level of the subsector in question. Infrastructure, facilities, and professors availability and standard of living of students' families determine the studying condition factor (SCF). In the same way, infrastructure, facilities, and professor availability and training potentiality define the training condition factor (TCF). The two factors critically influence the graduation rate, the school leaving rate of the students and the profession leaving rate of the computer personnel. When SCF is equal or near 0 most of students leave education institutions without having graduated. When it is near 1 (better studying conditions) more students graduate every year and enter the computer personnel profession; almost nobody leaves school without graduating. When TCF is equal or near 0 computer personnel leave the profession after a short period. The rapid development of IT makes them "obsolete", since they do not train regularly in using the new products.

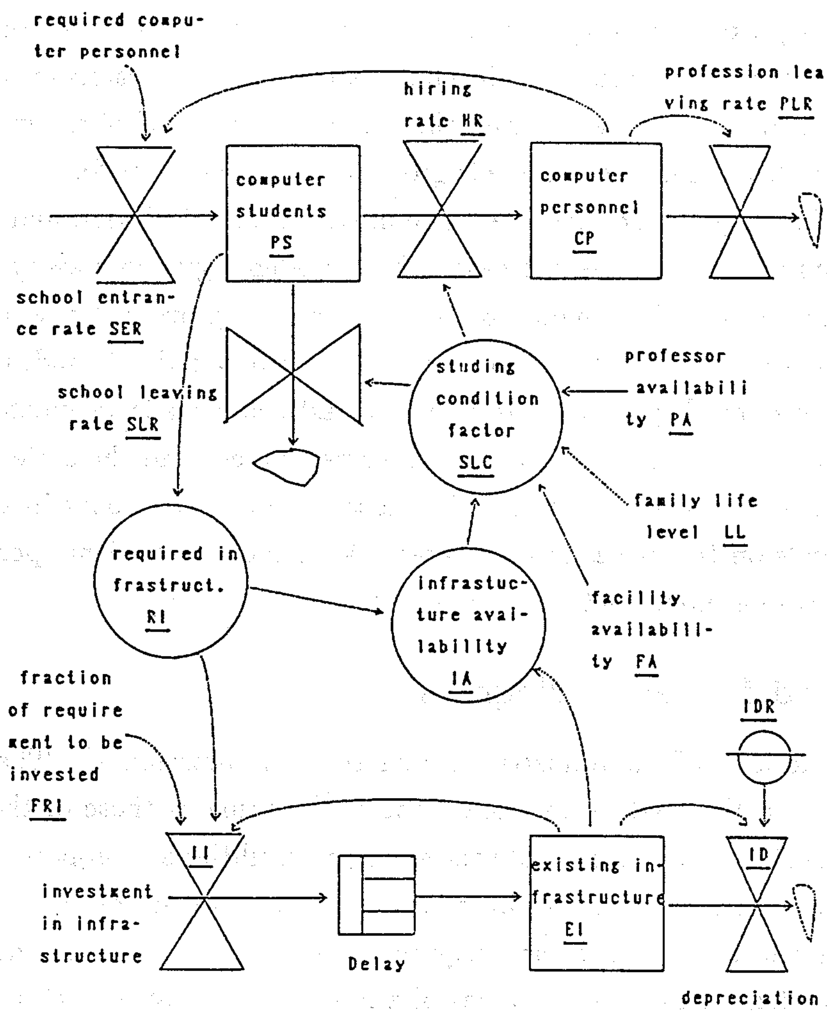


Figure 3 : Simplified Flow Chart of the Model

Figure 4 reports the curves of school leaving rate(2), graduation rate(1) in function of SCF and profession leaving rate(3) in function of TCF.

The related mathematical expressions are the following, respectively.

(1) $\mathrm{slr.kl} = \mathrm{ps.k} * \mathrm{lr.k}$

(2) $\mathrm{lr.k} = 1 - (1 - (1 - (\beta_1 \mathrm{pa.k} + \beta_2 \mathrm{fa.k} + \beta_3 \mathrm{ll.k} + \beta_4 \mathrm{ia.k}))^{\mathrm{n}})^{1/\mathrm{m}}$

$\beta_1, \beta_2, \beta_3, \beta_4$ designate the proportions of professor availability, facilities availability, standard of living of students' families, and infrastructure availability in SCF respectively. In the model, .4, .3, .2, and .1 have been used respectively for these proportions. Many values are tested for n and m; n=m=5 suit better to the simulation results.

(3) $\mathbf{hr.kl = ps.k * gr.k}$

(4) $\mathbf{gr.k = \theta * (1 - exp(-\alpha(\beta_1 pa.k + \beta_2 fa.k + \beta_3 ll.k + \beta_4 ia.k)^2))/(1 - exp(-\alpha))}$

θ expresses the limit value of the graduation rate. For system engineers θ is equal to .2. That means a maximum of 20% of students graduate every year. α indicates how quick the graduation rate reaches the limit value.

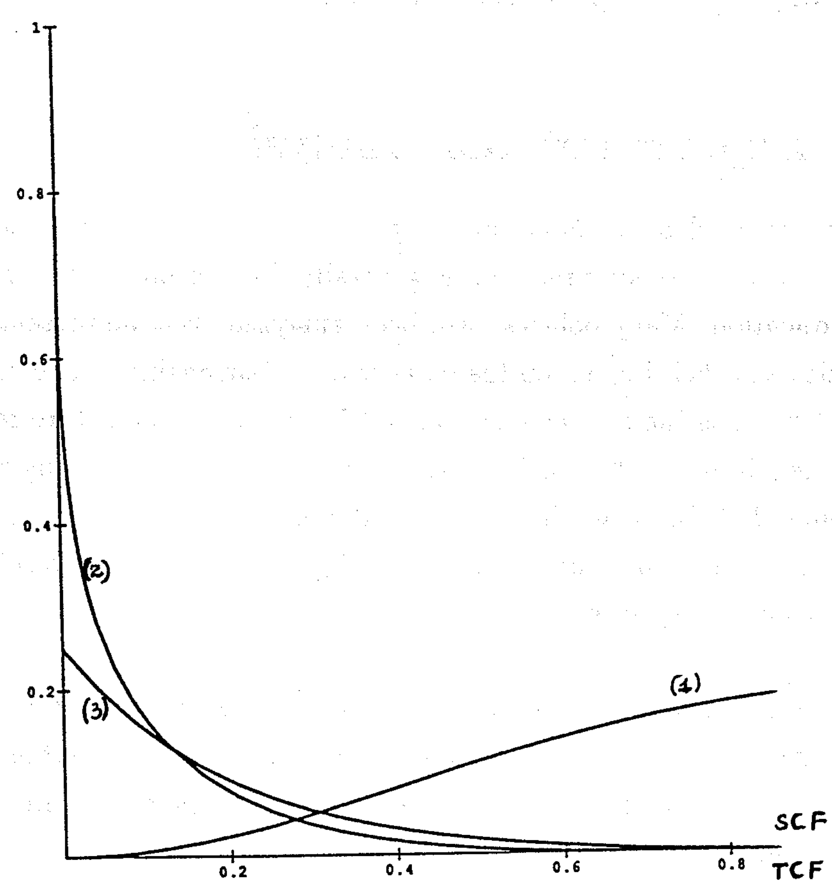
(5) $\mathbf{plr.kl = cp.k * por.k}$

(6)

$$\mathbf{por.kl = \lambda * \frac{cosh(\mu((\gamma_1 tp.k + \gamma_2 pa.k + \gamma_3 fa.k + \gamma_4 ia.k) - 1)) - 1}{cosh(\mu) - 1}}$$

$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ designate the proportions of professor availability, facilities availability, training potentiality, and infrastructure availability in TCF. In the model, .4, .3, .2, and .1 have been used for these proportions. λ designates the inverse of the maximum time a worker spends in the profession in the case of no training.

Figure 4 Graduation rate(1), school and profession leaving rates(2)(3)



Tests suggest 5 as better value of μ. An existing asset can become greater than the required asset. So the related ratio becomes superior to 1. But even in this case the effect of this ratio on SCF or TCF remains the same as when it is equal to 1. Therefore, in the equations (2), (4), and (6) the five ratios have the following expressions.

(7) $\mathbf{pa.k = (1 + (pf.k/rpf.k) - |1 - (pf.k/rpf.k)|)/2}$
(8) $\mathbf{fa.k = (1 + (f.k/rf.k) - |1 - (f.k/rf.k)|)/2}$
(9) $\mathbf{ll.k = (1 + (hi.k/nhi.k) - |1 - (hi.k/nhi.k)|)/2}$
(10) $\mathbf{ia.k = (1 + (i.k/ri.k) - |1 - (i.k/ri.k)|)/2}$
(11) $\mathbf{tp.k = (1 + (trp.k/rtrp.k) - |1 - (trp.k/rtrp.k)|)/2}$

The above relations are translated in dynamo expressions by the following clip functions.

(12) $\mathbf{pa.k = clip((pf.k/rpf.k), 1, rpf.k, pf.k)}$
(13) $\mathbf{fa.k = clip((f.k/rf.k), 1, rf.k, f.k)}$
(14) $\mathbf{ll.k = clip((hi.k/nhi.k), 1, nhi.k, hi.k)}$
(15) $\mathbf{ia.k = clip((i.k/ri.k), 1, ri.k, i.k)}$
(16) $\mathbf{tp.k = clip((trp.k/rtrp.k), 1, rtrp.k, trp.k)}$

3 Policy Experiment and Analysis

To satisfy the demand of industry for computer personnel, students must be educated. The investment effort for education is generally done in infrastructure, facilities, and professors education. Many policies have been analyzed. But we present only three investment policies and their impact on the balance of system engineers and required system engineers. Policy 1 is the common case in ADC. 50% of infrastructure requirement, 30% of professor requirement, 20% of facilities requirement, 10% of training requirement are met. In policy 2, 50% of all the requirement are met. In policy 3, 100% of the requirement are met. Figure 5, figure 6, and figure 7 give the simulation results of policy 1, policy 2, and policy 3 respectively.

In policy 1, since no investment is done during the simulation time, the initial value of the facilities fixed asset depreciates to zero value. Almost no new system engineers enter the profession. At the same time industry demand for personnel and investment requirement increase.

Figure 5: Policy1

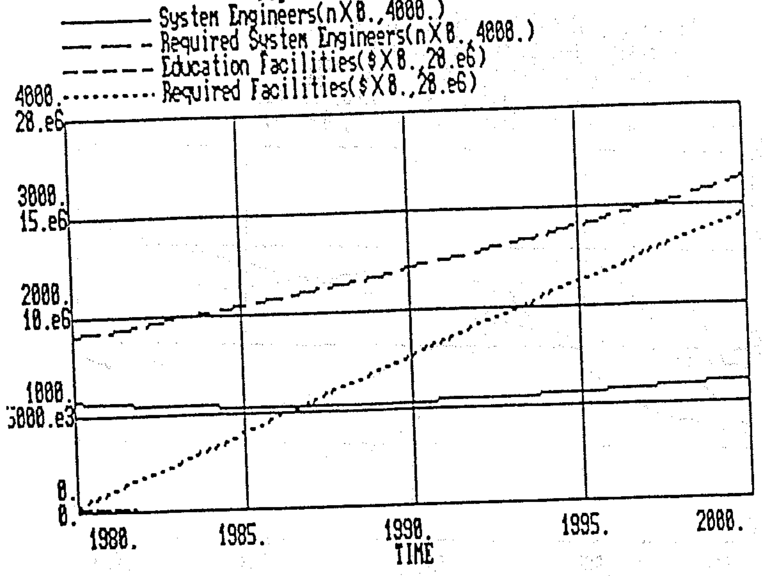
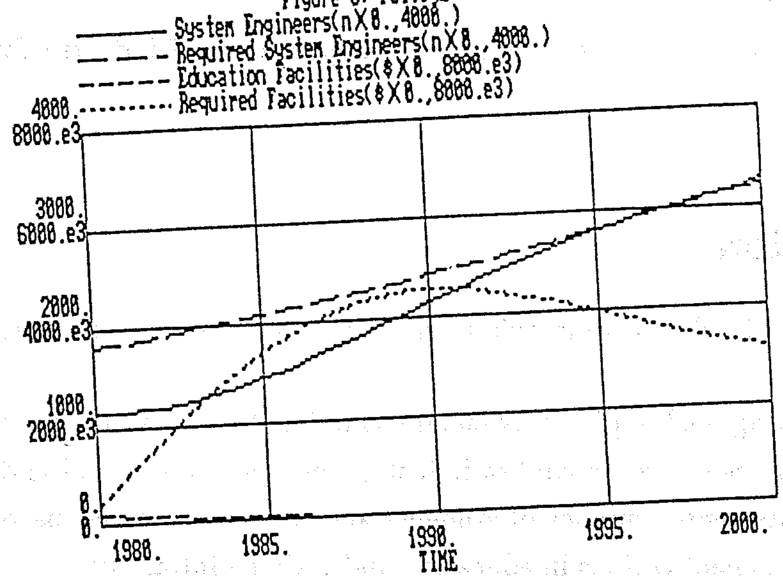


Figure 6: Policy2



The gap between system engineers and required system engineers increases. In policy 2, certain amount of investment is made. Educated and trained personnel is provided to industry. System engineer requirement is met from year 1994 only. At the contrary in policy 3, every year, investment is made to satisfy the requirement of all the subsectors. Standard of living of students' families increases to acceptable level. Organizations provide enough resources for training of their personnel. Figure 7 shows that the fixed asset of facilities subsector increases and oscillates around the requirement curve, since investment actions are stopped when the existing asset becomes greater than the required one. Also system engineer curve oscillates around the demand curve.

These oscillations are due to the education time of the students. As a result of policy

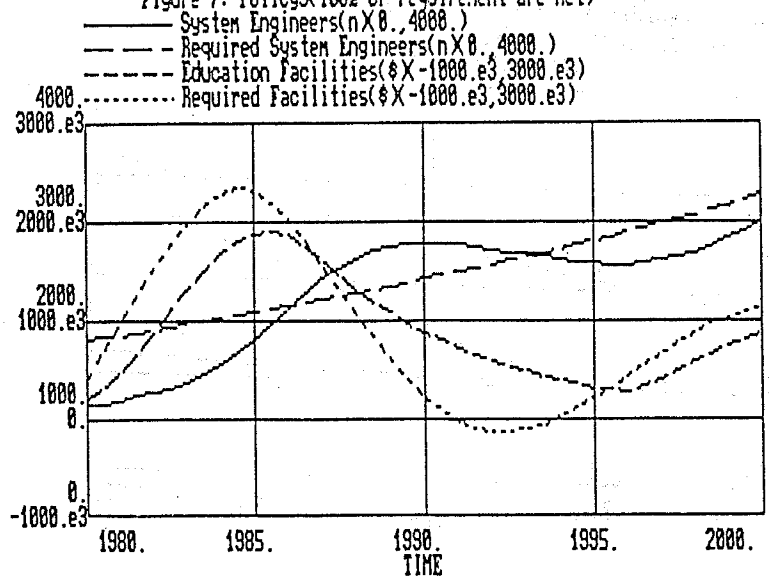


Figure 7: Policy3(100% of requirement are met)

3, graduates of education institutions meet the requirement of industry for computer personnel.

4 Conclusion

Some lessons can be drawn from this modelling experiment for managers of the IT field in ADC.

- Instead of leaving the law of supply and demand free to operate like in most western developed countries, the demand of industry must be investigated and, according to these requirements, number of students and professors should be planned and educated, investment actions in education and training infrastructure and facilities should be done. All these education and training actions must be performed in the framework of national and general education policies designated to closely match the global development requirements (in terms of manpower) and the national education effort.
- It is not enough to just build education infrastructures, buy facilities and educate professors. The resources allocated to the different subsectors(infrastructure, facilities, professors, training resources, etc.) must be enough to ensure a good level of computer personnel. The average standard of leaving of a student's family and resources allocated by each organization to train its workers must be taken into account in the IT education policy design and implementation.

Also the sensitization of the general population to the advantages and the drawbacks of IT on the nation's development process must be done. The impact of computer installations on organizations' productivity depends not only on the availability of computer personnel in terms of number and quality but also on the degree of awareness of those who use these systems.

References

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