TOWARDS A TRANSITION TO A KNOWLEDGE ECONOMY: HOW SYSTEM DYNAMICS IS HELPING SARAWAK PLAN ITS ECONOMIC & SOCIAL EVOLUTION

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Abstract

Accounts of the real-world use of system dynamics as a policy evaluation tool in macro-economic management are relatively rare. This paper offers an overview of current research being undertaken for the government of the State of Sarawak in E. Malaysia where an SD model is being formulated to inform the State's future economic and social planning to 2020. Although still a work-in-progress, enough has been achieved to enable an interim account of the research to be written. Positive engagement with State government officials at the highest level has put system dynamics on the map in this corner of SE Asia.

Introduction

This paper reports on the progress to date in formulating a system dynamics model designed to provide a planning aid which can be used by senior state officals and ministers in discharging their role in steering the development of the State of Sarawak in East Malaysia.

Sarawak is a former British colony which is now part of the federation of states called Malaysia whose capital, Kuala Lumpur, is situated in West Malaysia. The outlying Malaysian States of Sarawak and Sabah are in East Malaysia on the island of Borneo (see map figure 1). Adjoining nations here are Brunei and Kalimantan (Indonesia). The capital of Sarawak and the seat of government for the State is Kuching near the north-west coast.

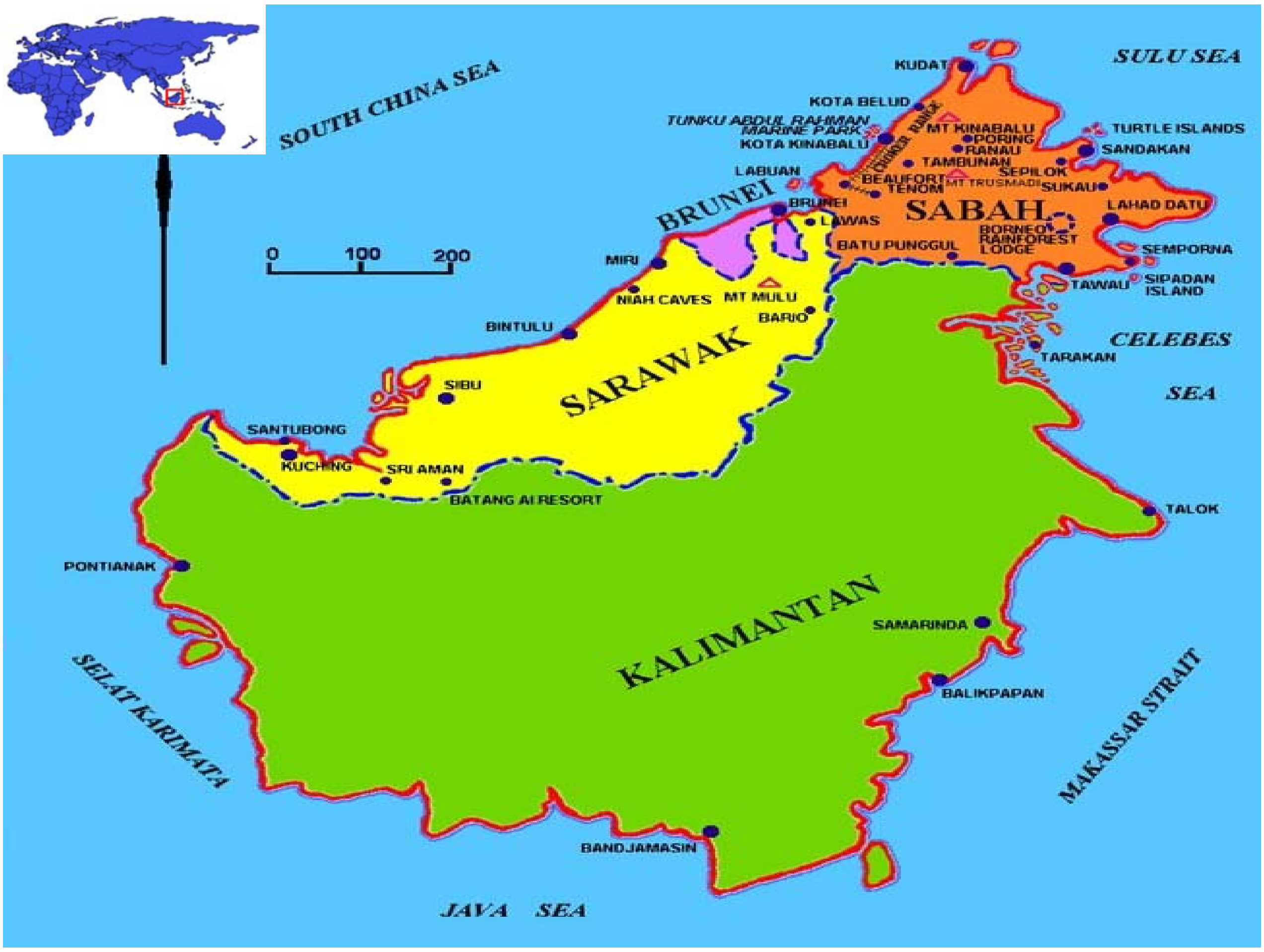

Figure 1: Map of the island of Borneo

The study is a work-in-progress and this paper reports on developments to date. Conclusion of the research and presentation of the final report is anticipated in October 2005.

Tools for Economic Modelling

There are three other principal tools and modelling methodologies currently used for development planning purposes apart from SD, namely spreadsheets, Input-Output tables and econometric models. Each methodology has its merits and potential usefulness as an aid to specific aspects of the development planning process, but they are distinctively different in terms of the input requirements, the type of data used, how the results are used and, most of all, the modelling purpose. A good overview of the methods itemised below, and how they differ from SD, can be found in Meadows and Robinson (198?). Fundamental to the choice of methodology is the need to define the purpose of the model, termed problem definition, and for this purpose to be agreed by all parties concerned.

Spreadsheet Modelling As the name suggests, the basic framework to represent the economic activity is that of a spreadsheet depicting relationships. Characteristics of this methodology are large discrete time steps in the analysis, no direct incorporation of feedback mechanisms, and exogenous inputs are utilised. Examples here are the World Bank's Revised Minimum Standards Model (RMSM), which forms a spreadsheet comprising of 10 columns and 5000 rows.

Input-Output Tables This is a well known methodology which measures flows in money or goods amongst various sectors of an economy in a given year. This is, therefore, essentially a static or snap-shot model. It uses only directly observable economic data and presents a record of what did happen. Linear input-output relationships are assumed, and there is no representation of delays or bottlenecks in economic activity. The models are of value in highlighting the historic order of magnitude of the cross impacts of various economic sectors.

Econometric Models. These are the most mathematically intensive form of modelling, and are based upon economic assumptions and theoretical economic relationships between variables of interest. Past data is used to estimate parameter values. In fact, an extensive set of past time series data is needed for parameter estimation purposes, and model quality is based upon how well the model fits the data. Econometric models are used for forecasting, but are inappropriate when conditions might deviate from those in the historic period used for parameter estimation.

The "Threshold 21 (T21)" Model

The "Threshold 21" model (T21) is a large system dynamics based model for national planning in developed and developing nations (Barney, 2003). It has been progressively enhanced since its initial formulation in the late 1970's.

It is a generic and flexible economic planning model in that it purports to be applicable to any country and can be customised to that country's particular situation. Custom applications have been made to *inter alia* Bangladesh, China, Ghana, Italy, Malawai, Somalia, Tunisia and the USA. (Ref ISDC Oxford).

In 1999 the President of the World Bank introduced the Comprehensive Development Framework (CDF) detailing a holistic approach to national development and which effectively replaced the former Country Assistance Strategy (CAS) the World Bank had hitherto supported. The CDF engendered new criteria and standards for national development models.

The T21 model most probably meets the new standards and certainly exceeds the capabilities and utility of the spreadsheet based models used for some time by the World Bank and the IMF. However, being an 'off-the-shelf' model implies that T21 is *not* principally designed for addressing specific issues concerning economic development which pertain in a particular country.

For this reason it was considered more suitable to formulate a bespoke SD model designed to focus on an agreed issue (see below). In addition, in the case of Sarawak, we were concerned with a State and not a nation and needed to specifically tailor any model to handle the State's interface with the federal government.

Engagement with System Dynamics

Given the preponderance of the above methodologies, it was difficult initially to secure acceptance of the SD approach (Forrester, 1961; Coyle, 1996; Sterman, 2000). Admittedly there had been relatively little modelling activity undertaken in Sarawak, the state government perhaps being willing to accept that the centre of gravity for analysis and research resided in the federal capital, Kuala Lumpur. Here there was a tradition of using econometric and input-output analyses and so knowledge of these methods had gained a certain amount of currency amongst officers in Sarawak.

Prior to the contract being signed a number of visits had to be undertaken to explain the nature of SD and to attempt to engage the state government such that they went ahead with the contract. This took nearly two years but ultimately they decided to go ahead and the contract was signed in June 2003. In retrospect this can be seen as quite a bold step especially as the State Planning Unit (the contact unit) had hitherto seen its role solely as provider of (extensive) statistical data and its rudimentary analysis. It might have taken a lot less effort to engage them with econometric modelling, but it was felt that SD had a great deal more to offer. Perhaps a pivotal moment in their acceptance of, and subsequent enthusiasm for, SD as a methodology was when they had the opportunity to see a prototype model actually running complete with stock-flow diagrams and graph plots. The software tool employed was Vensim™ and seeing the reaction to the SyntheSim™ feature was quite illuminating.

It was considered quite appropriate to display views direct from the software. Whilst scrutiny of equations was avoided, government officers could easily follow the ideas in the flow diagrams and critically comment where they felt something had not been properly specified. In particular they were vocal in situations where our chosen nomenclature for variable naming was inconsistent with their usage and this criticism was encouraged as it demonstrated that they could contribute to the emerging model.

Determination of model purpose

The determination of a purpose for an SD model is well grounded in the literature. Here a brief had been agreed: to provide the state with a tool to aid their future economic planning. But this is too broad an objective. A specific purpose needed to be defined and a period of time was spent after the commencement of the research in reviewing the various strands of thinking in the state government and, in particular, reading the key speeches of ministers to see what was preoccupying them. There would be no benefit derived from the creation of some grand planning tool if it was not consonant with the interests and ambitions of the primary stakeholders.

A proposal was eventually tabled and agreement secured to develop the model with the following purpose:

> **How and over what time-scale can the State of Sarawak best manage the transition from a production-based economy (p-economy) to a knowledge-based economy (k-economy) and thereby improve international competitiveness?**

There had been concerns raised in ministerial speeches that the resource-based economy, which had served Sarawak well in over two decades of development, was coming under pressure from other industrialising nations, in particular China. To secure further international competitiveness the state needed to develop more high-tech industry with higher value-added products and services: in short there was a desire to shift towards a k- economy, implying the emergence of a quaternary sector.

A High Level Map

The diagram shown in figure 2 attempts to set out, in as economical a way as possible, the overall structure of the prototype model designed to address the issue above.

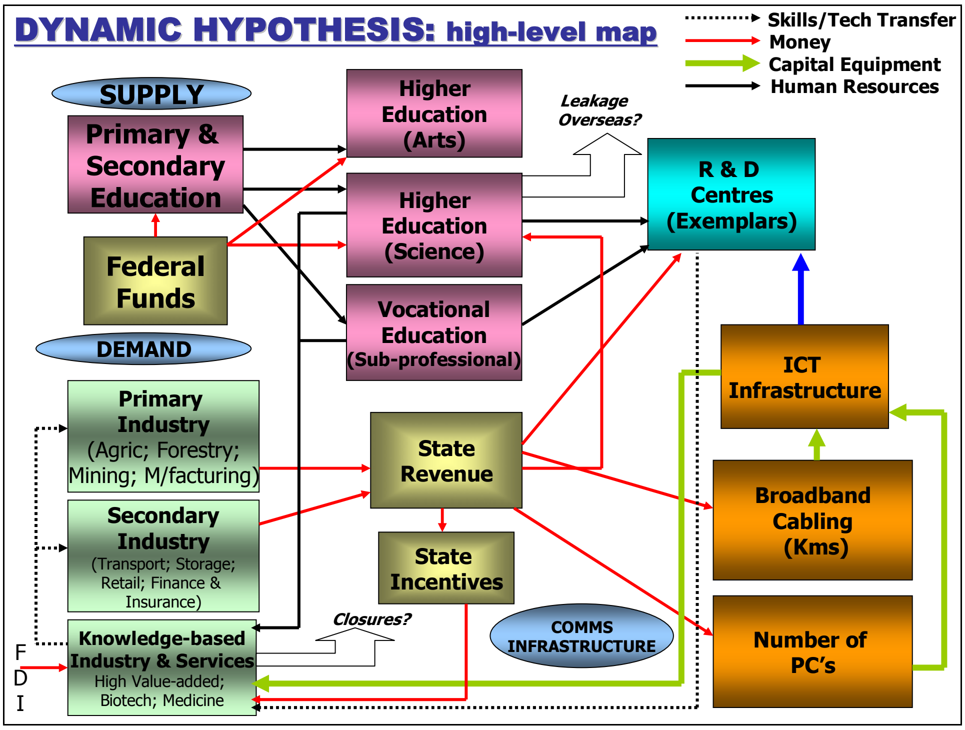

Figure 2: A proposed high-level map for the emerging model

There are three main foci:

- The supply of suitably trained human capital and entrepreneurs.

  This is the output from the education sector shown towards the top left of the diagram. Clearly the primary and secondary education sector provides the output of students some portion of which will progress to higher education. Both arts and science specialisms are represented and there are indications that the balance here does not currently favour the enhancement of science skills which underpin the k-economy. The current graduate output ratio is weighted heavily in favour of arts courses. Approximately only 20% undertake a science degree, with around 20% of those graduates undertaking teacher training.

  The vocational sector is also represented since development of a k-economy is augmented by an important group of sub-professionals (e.g. technicians) who have a crucial supporting role to play.

  Funding for most education in Sarawak is provided by the federal government. However, and primarily in an effort to develop the science base, the State Government have funded certain private university developments. State funding in this manner can play an important part in expediting the flow of suitably qualified individuals who will stimulate the development of a k-economy.

- The demand side of a k-economy: those knowledge-based industries and services which are emerging (in some cases as development of primary and secondary industry) to form an ever-increasing component of the economy.

  The sectors towards the bottom left of Figure 3 are split into Primary (the production and resource based sector also called the p-economy); Secondary (the service sectors such as tourism, finance and professional services); and the knowledge-based sector (the k-economy or quaternary sector).

  The evolution of the quaternary sector is propelled by a mixture of foreign direct investment and State funding. But this alone is insufficient, for a flow of skilled human capital is essential as is the quality of the ICT infrastructure which must have attained an appropriate level of sophistication.

  The growing emergency of a quaternary sector can appear to consume resources which might otherwise have been directed to primary and secondary industry. But it must be stressed that, contemporaneously, development of the k-economy will mean direct skill and technology transfer benefits to the existing base of primary and secondary industry. It is impossible to ignore the bedrock components of the p-economy which can, in turn, be enhanced as part of overall economic development. The sectors are currently the main providers of state revenue (via taxation and employment) and are likely to remain so.

- The state of the ICT infrastructure, which in some senses mediates the evolution of the drivers of supply and demand.

  The quality of the ICT infrastructure can be fairly easily measured by appropriate metrics. Two such examples are the length of the broadband data highway within Sarawak and the estimated number of PC's installed.

  Again, it would be expected that the State government revenue would, in large measure, underpin the enhancement of these metrics, although foreign direct investment cannot be ruled out.

  An ICT infrastructure of reasonable sophistication will also be necessary in order to allow the development of a number of Research and Development (R&D) Centres of Excellence, as indicated in Figure 2. The initiation of such projects is suggested in order that best practice k-economy activities can be showcased and publicised. These centres will make it clear that the State government is strongly promulgating the development of the quaternary sector through provision of funds to allow these start-up operations to proceed.

Development of a k-economy would be constrained if the supply of science graduates and suitable sub-professional k-workers are not forthcoming, which is why emphasis has been placed upon coincident (or even prior) educational changes. Initial staffing of such centres may be a problem but it is possible that, with sufficiently attractive remuneration packages, qualified Sarawak expatriates would be tempted to return.

The proposed R & D centres can be seen as crucial catalysts in the stimulation of the quaternary sector and they will offer a primary supply of people with the necessary skill sets to enthuse the creation and development of knowledge-based industry and services.

The dynamic flows to be considered are:

- Skills and technology transfer
- Money and all forms of financial resource
- Capital Equipment
- Human Resources (Capital)

Within the industry sectors (particularly the Primary Sector) there are also dynamic flows of goods, material and orders.

Transformation to a k-economy: the Challenge

The high-level map suggests that the three components of: supply, demand and the ICT infrastructure need to be broadly in balance if the transition to a k-economy is to be achieved smoothly. Any mis-alignment in this triangulation will most likely lead to fluctuations in progress and during any downturn there may well be political repercussions.

Consider the hypothetical scenarios shown in figure 3.

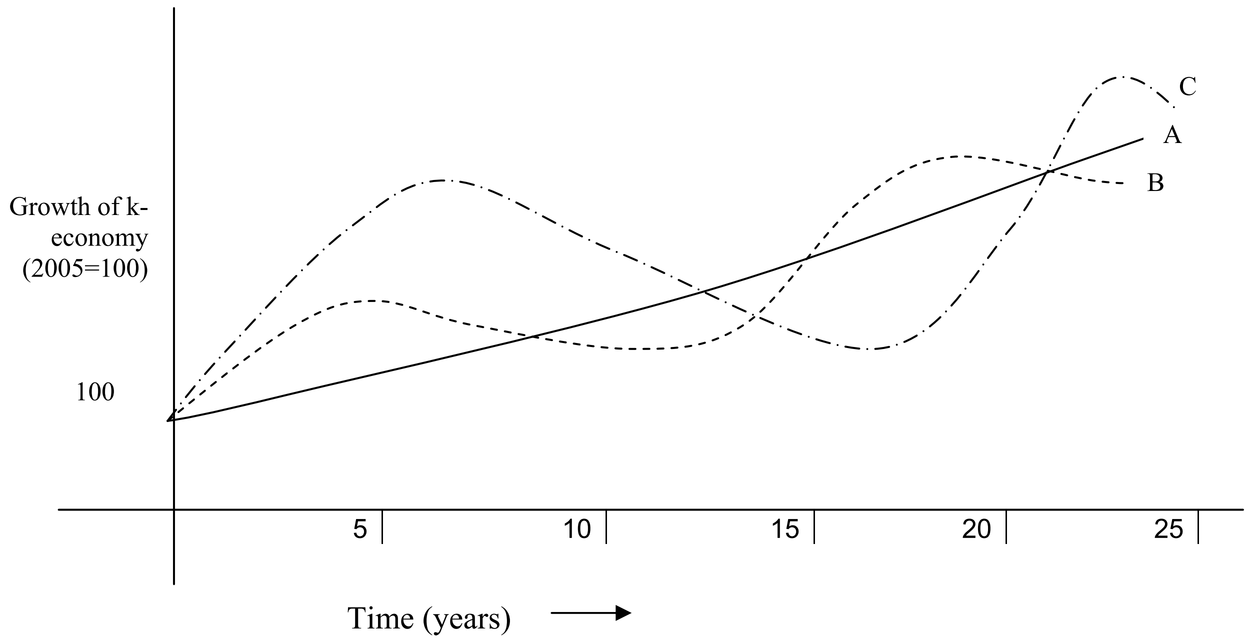

Figure 3: Hypothetical scenarios for the growth of the k-economy component

Scenario A is an ideal case. There is a smooth growth progression suggesting an effective triangulation.

Scenarios B and C achieve growth, but it is uneven. Economists call this 'higgledy-piggledy' growth. In the case of scenario C there is an alarming medium term crisis while the components adjust and, while this scenario may be something of an exaggeration, if such an out-turn should manifest itself it is possible other dynamics (maybe political) will emerge during the downturn. This may effectively stifle any further progress.

Figure 2 suggests the possible ramifications arising from a lack of balance between the three components (see the unshaded wide arrows).

- Should the supply of qualified k-economy human capital substantially exceed the capacity of the Sarawak economy to utilise such skills then these people would likely move abroad to further their careers ('leakage overseas' in figure 2). There are suggestions that to an extent this has already happened and hopefully positive future developments in Sarawak will attract them back.

- Should the emergence of high-tech industries (higher value-added), funded by foreign direct investment and state and federal government monies, race ahead of available skills, then Sarawak might see wholesale closures of schemes or a series of white elephants until balance has been restored. It is arguably the case that this 'excess demand' would have more serious repercussions than 'excess supply'.

- The ICT infrastructure, the third component of the triangle, is a necessary, but not sufficient, condition for the emergency of a k-economy component in Sarawak. Without such an infrastructure (indeed without the provision of electricity – a relevant condition in some geographically remote parts) the k-economy cannot even be initiated. But its over-rapid development leads to wasted resources, since much of the funding for this infrastructure will likely come from government.

Remember competing uses for this funding extend across the entire range of social, health and poverty reduction policies of the state. It is important to ensure that funds spent on developing the ICT infrastructure (which may initially be located in the urbanised areas in the north and west) do not lead to alienation by certain other groupings who might prefer funds to be spent elsewhere.

Current status of the model

The model presently consists of the following sectors:

- Population
- Education & Human Capital
- Workforce (including certain measurement indices)
- R&D/ ICT Infrastructure / k-firms
- Manufacturing (incl Electrical & Electronic); Services (incl tourism) & GDP
- Timber (including downstream processing)
- Palm Oil: trees
- Palm Oil: products
- Liquefied Natural Gas & petroleum production
- Sago production
- Government finance

It is not possible to cover all of the sectors developed thus far and attention is given just to the Education & Human Capital sector along with the Workforce sector since these areas have a primary role in the evolution of a k-economy.

Education & Human Capital

Progression to a k-economy will take some time but will be propelled by the twin thrusts of investment in people and a communications infrastructure. Because of a desire to focus upon the achievement of a suitably qualified labour force, it was considered that the model needed to feature the output of higher-educated and technically-qualified human capital (see figure 4). These developments underpin a suitably skilled workforce and, in view of the importance attached to this, a workforce sector was also formulated.

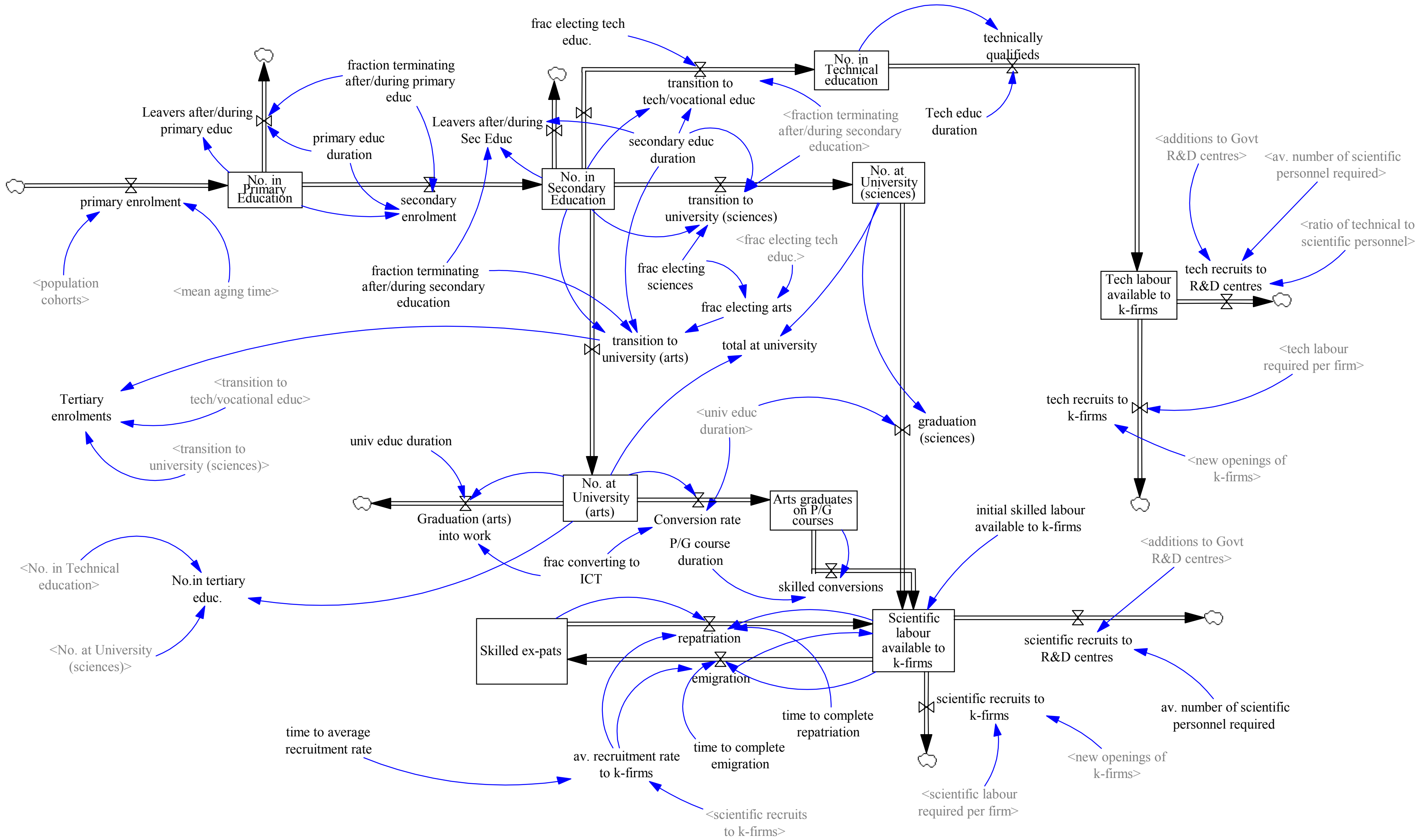

Figure 4: Education and Human Capital Sector

Technical education is included. Knowledge-based firms require both skilled scientific staff but also technical support staff who would gain qualifications from the technical/vocational education institutions existing in Sarawak.

In addition to emigration, a flow of repatriations is included. If the prospects and opportunities for skilled ex-patriots expand in Sarawak then it would be expected that some fraction would return to their homeland for employment and career progression. This will add to the skilled labour available to k-firms and is depicted in the flow diagram for this sector (see figure 4).

Those leaving before, during and just after primary education (P1 – P6) are explicitly included because such individuals do join the workforce ultimately. The reduction of the numbers of these dropouts is an important policy issue in the context of this research. There are also a number who terminate formal education either during or following secondary education (F1 – F5). In fact the definition of secondary education is taken to include the 6^{th} form (F6) for our purposes as the skill set, although higher in F6 pupils than F5, is some way short of that of a graduate or technician who can directly contribute to the development of a k-economy.

The imbalance between science–based and arts-based students at university is accepted and an assumption had to be made about this imbalance. From what little data existed on course choices, it appeared that around 60% choose an "Arts" course (used to represent a non-science course) whilst 20% take the science route with a further 20% opting for a technical education post-Form 5/6.

Arts graduates can be re-trained and the existence of post-graduate conversion courses to equip them with some of the skills needed in knowledge-based employment is included in the sector. This initiative needs to be progressed and it assumes a capability and willingness of the universities to mount it and, furthermore, government funding may also be required. In the event that (more) such courses are operationalised, there is yet another source of skilled labour available to k-firms.

The inclusion of a population sector means that the initial flow of pupils into primary education is taken from the outflow of the age band 2-4 yrs modelled within the population sector. Although school starts at seven years in Sarawak, this is the mid-point of the next age band (5-9 yrs) and it is felt that the numbers flowing out of the 2-4 yrs band would not be significantly different from those emerging post 6yrs.

Workforce Sector

This aims to portray the quality of human capital available in the Sarawak economy (see figure 5). It defines five categories consistent with their highest level of educational attainment.

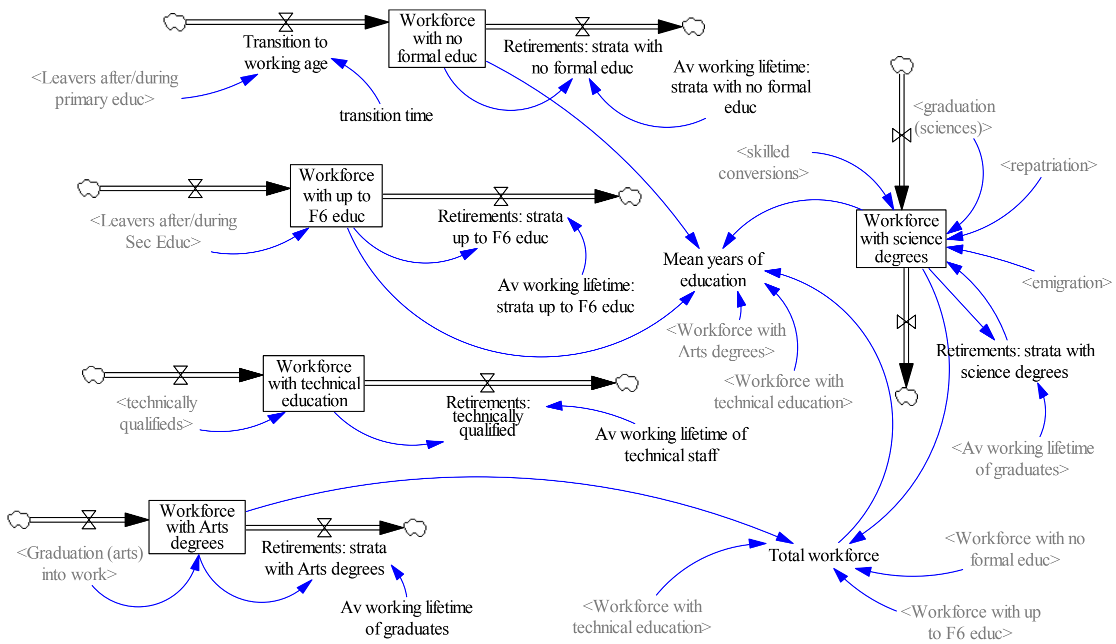

Figure 5: Workforce Sector: main view

The five categories are:

- No formal education
- Educated up to F5/F6, including F3 to Technical school
- Technically educated post F5/F6 (Certificate & Diploma students)
- Numbers with Arts degrees
- Numbers with Science degrees

The category ‘No formal education’ is those who have dropped out during or just after primary education (P1 –P6) or before commencing F1. Attaining this level of education alone cannot be expected to help a move to a k-economy and so the description is justified.

Those in the category ‘Up to F5/F6’ education similarly have terminated their education either during F1 – F5, after F5 or after F6. Tertiary education comprises those who have gone on to further or higher education post F5/F6. It includes those in degree level education, together with those electing a technical education. The latter have an important supporting role to play in the development of a k-economy.

Specimen runs of the prototype model

Increase in % of students studying science at University (Example 1)
An initial run assumed that the percentage of students studying science at university increases from 20% to 60% over a 10 year period. Suppose this transition rate is significantly accelerated. The strip graph at figure 6 shows the consequences.

The graphs show adjacent relevant variables from the stock-flow diagram in figure 4. The graduation rate in sciences has increased by about 5,000 persons per annum by year 20, but only 1,000 of these graduates end up in k-firms with around 4,000 per annum emigrating.

The reason for this is that the lack of availability of ICT resources, and consequently the growth of k-firms, is now the primary determinant of capacity. There are too few opportunities relative to the skilled graduate output, with the consequence that around 80% move to take suitable positions overseas.

Higher % growth rate for transition to sciences is better but higher emigration

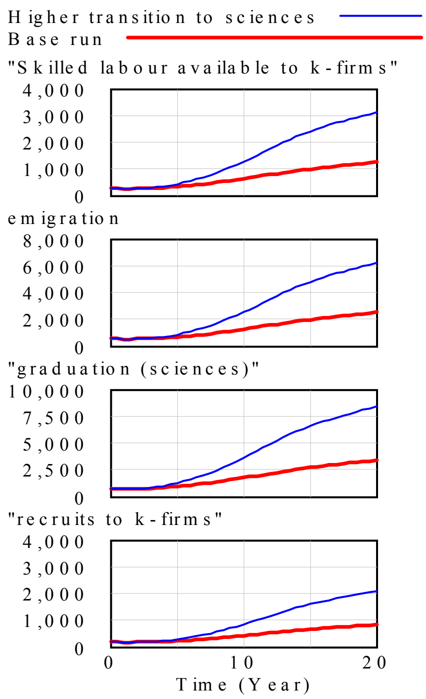

Figure 6: Strip Graph of higher % growth rate for transition to sciences

Delaying the Shift to Science (Example 2)
The shift to sciences at university is set to start at year t= 2. But suppose political and/or financial considerations delay this start date by a further two years. The

comparison graph shown as figure 7 enables an assessment to be made of the effects on new openings of k-firms. Initially, around 5 new k-firms are being created each year and by year 20, on the base run assumption of a start date of year t= 2, this has reached just over 15 new openings per year. The delayed start date for the policy shift has not had a serious effect on new openings. In the middle years there is a slight reduction relative to the base run case but by year 17 there is hardly any discernible difference between the effects of the two start dates on new openings of k-firms.

The reason for this is that there is less emigration under the delayed start. The outflow of new science graduates does not overwhelm the system's ability to absorb them into suitable posts – hence a smaller emigration rate. The *skilled labour available to k-firms* can, towards the end of the revised run, match that of the base run, allowing new openings of k-firms to ultimately coalesce with that of the base run.

It should be realised, however, that the above refers to new openings per annum. The cumulative total of k-firms in existence in the economy is lower under the delayed start time for the shift to sciences.

The final plot on figure 7 reflects the greater transition rate in the shift to sciences described in Example 1 above. Here the start date of the shift is the same as for the base run (t= 2). Obviously there is in excess of a doubling of new k-firm openings in this scenario but recall the message underlined in 1 above. The 1,000 or so extra graduates p.a. by year t= 20 has allowed around an extra 20 or so new openings of k-firms, but it also propels an additional emigration rate of 4,000 persons p.a.

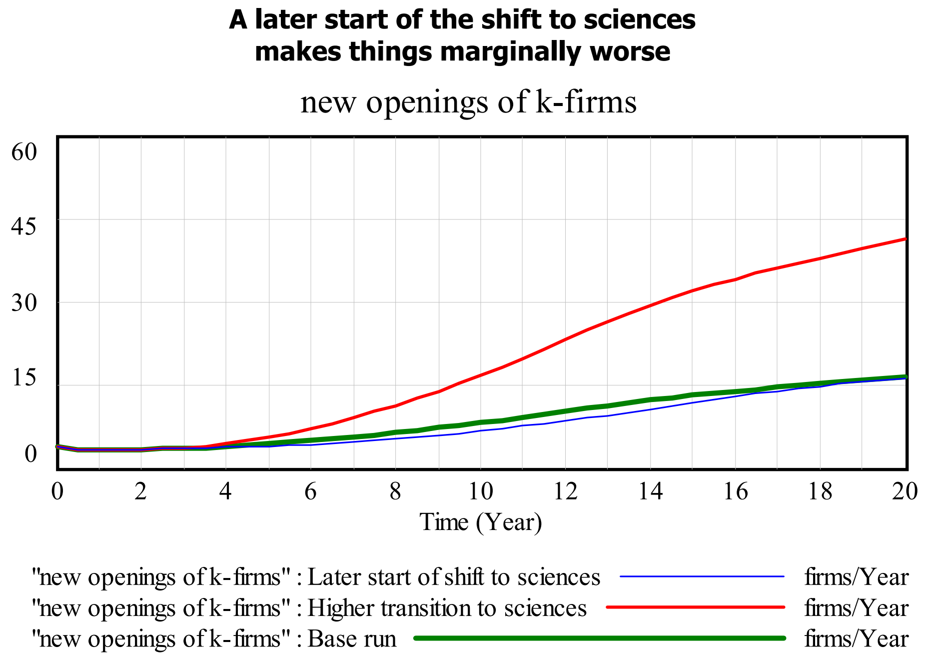

Figure 7: New openings of k-firms under three policy scenarios

Provision of ICT Resources (Example 3)
A third illustrative experiment revolves around the provision of ICT resources. If this provision is undermined from the start then the ICT infrastructure becomes the constraining variable with the consequences for new openings of k-firms as shown in figure 8.

Initially, it is assumed that the stock of available ICT resources (measured in arbitrary I-units) is 2000 and increases at the rate of 1000 I-units per annum. On the assumption that the average ICT resources required per new k-firm is 100 I-units, this means that, at most, a minimum of 20 new k-firms per year could be opened in the early years. However, the fact that this does not happen is because the initial skilled labour availability is set at 300 persons with an average requirement per k-firm of 50 such persons. This means only 6 new k-firms can open in the early years, and each one is phased-in over a period. It takes time for any new firm to become fully operational.

The experiment portrayed in figure 8 involves cutting back ICT resources initially to as low as 500 I-units and assuming this increases by only 10 I-units per annum. With such a low and continuing provision of ICT infrastructure resources, it means that we see no more than around 5 new openings of k-firms per annum, recalling that each new k-firm is assumed to require 100 I-units. The ICT infrastructure is now the constraining variable (rather than skilled labour). The assumed change reveals that a considerable initial and continuing shortfall in ICT resources will clearly impede progress in development of a K-economy. Hardly any new k-firms are opening and emigration (not shown) is extremely high because skilled labour cannot gain suitable employment in the domestic economy. The message here is simple: ICT resources are a necessary but not sufficient condition for the emergence of a K-economy. Harmonisation of development in both factors of production – labour and capital – is required.

Cutting Back on ICT will definitely impede progress...

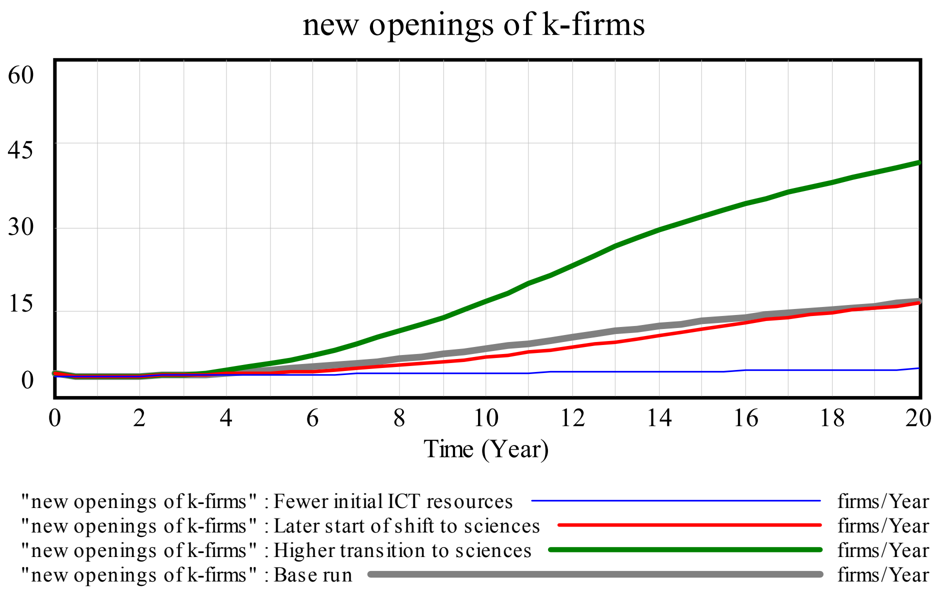

Figure 8: New openings of k-firms consequent upon fewer ICT resources

Numbers of Annual Enrolments at Various Stages of Education (Example 4)

It is also instructive to examine the numbers enrolling per annum at various stages of education. This gives an immediate view of the losses being experienced as successive phases of education are entered (see figure 9). It is the gap between the curves which needs to be minimised. Here, put quite starkly, is a critical policy issue in the education sector and one to which the Sarawak government needs to give urgent attention.

Given the duration of each phase of education, the curves should successively follow each other down towards the right of the graph. Further, ideally there should be only a small gap between each phase if a significant fraction of each cohort progress to the next level.

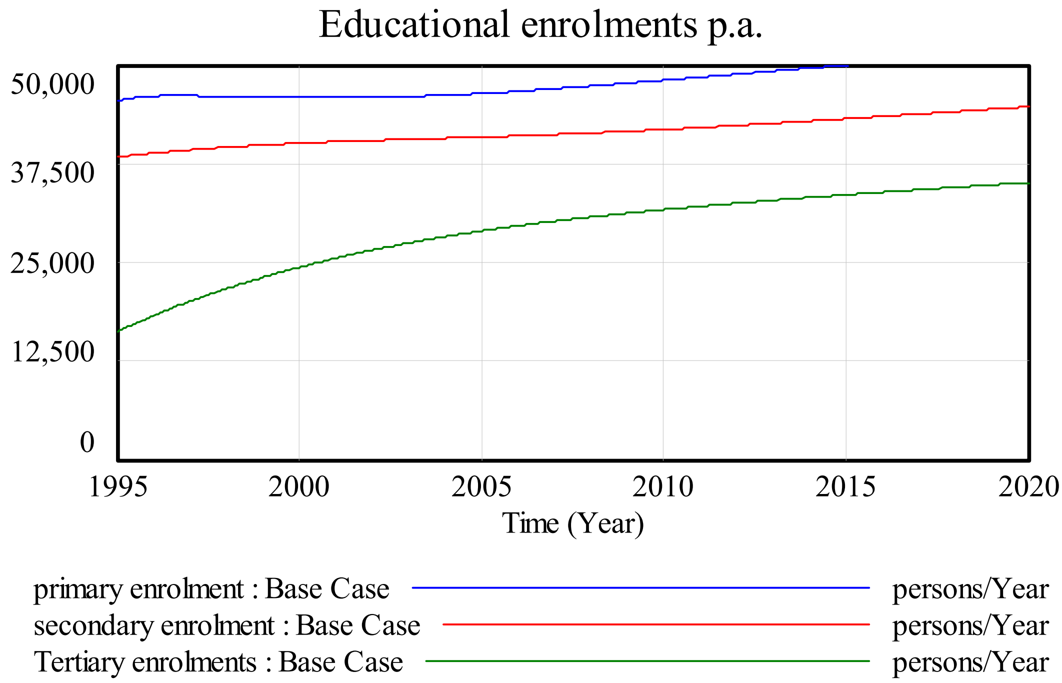

Figure 9: Educational enrolments at start of a phase of education (Base Case)

Birthrate Sensitivity Testing in respect of Annual Enrolments (Example 5)
Sensitivity to the assumed birth rate is an obvious consideration. The original assumption of a medium birth rate (19 live births per 000 population) in figure 9 differs little from the picture for a high birth rate (figure 10) in educational terms. Primary enrolments pass 50,000 p.a. just after 2010 in the high birth rate scenario whereas this is delayed to nearly 2015 in the Base Case (medium birth rate). In addition, differences in secondary and tertiary enrolments across the two figures are imperceptible. Clearly more than just demographic possibilities are part of a future agenda if the gaps between the curves are to be lessened. Proactive policy is needed.

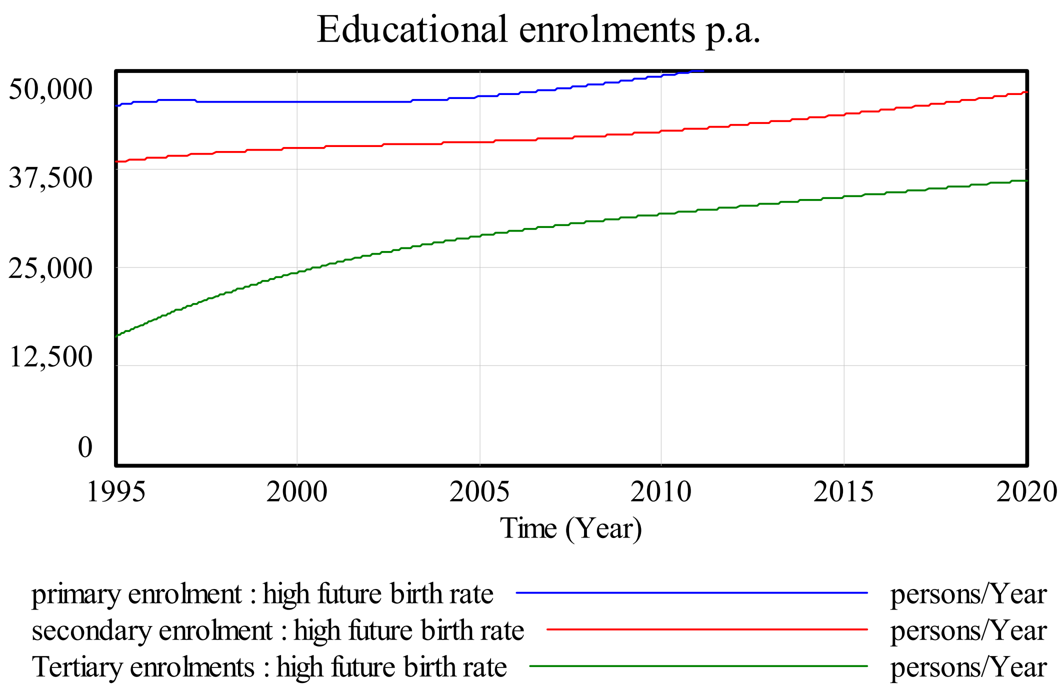

Figure 10: Educational enrolments at start of a phase of education (High future birth rate)

Calculation of the Mean Number of Years of Education (Example 6)
An important international measure of development is the 'number of years of education'. This is computed in the model. It weights the numbers in the various strata of education by the duration of each strata and divides by the total numbers being educated.

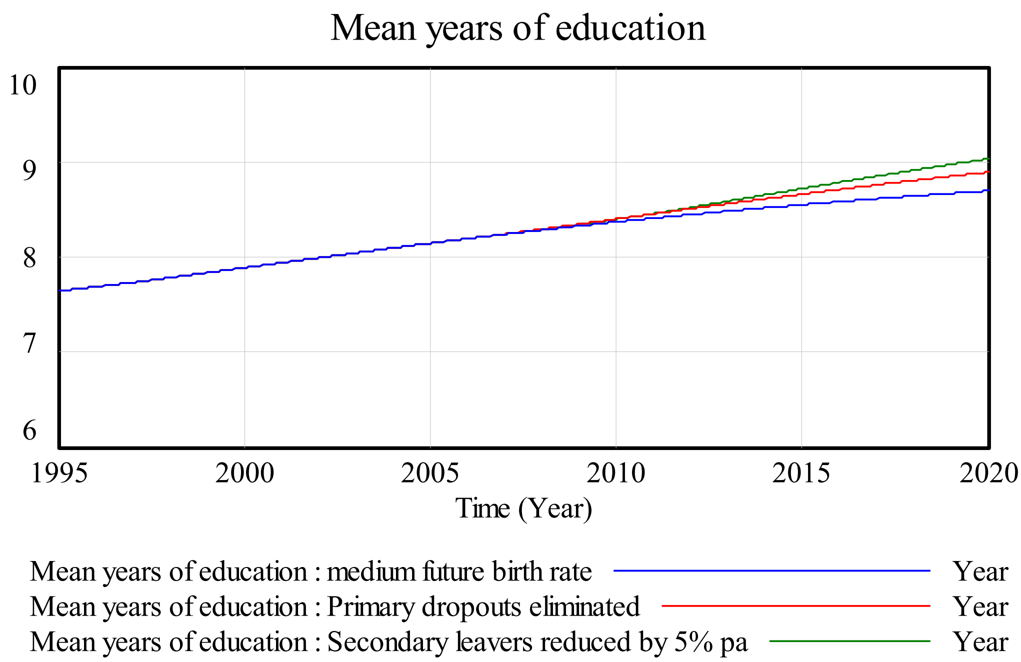

Figure 11: Effects of changes to school dropouts on mean years of education

The average number of years of education for Sarawak in 2005 (figure 11) is shown as just in excess of 8 years. This compares with some other nations as follows.

Nation	No of Yrs	Year attained
Singapore	8.1	2000
USA	12.2	1992
Japan	10.8	1992
UK	11.7	1992

Improvements are computed under two scenarios – firstly assuming the dropouts at the primary school level are removed altogether from 2006 and secondly that the dropouts and/or leavers at the secondary level are reduced progressively by 5% p.a. over the period to 2010, the termination date of the 9th Malaysian Plan (5-yearly cycles).

Leveraging change in this important international measure of development is clearly not easy. Although the reduction of 5% p.a. for secondary leavers and dropouts might be achievable, that of eliminating the dropouts (11%) at primary level at once is a much taller order. But even if these challenging changes could be achieved, the outcome is just a 0.3 yr increase in the mean number of years of education by 2020.

Conclusion

Despite this research being a work-in-progress, it is evident that some useful insights are capable of being unearthed and this augurs well for the successful completion of the work. Positive engagement with the various civil servants and government officials associated with the project has accelerated as they have come to appreciate the capabilities of the SD methodology and associated software. (After a recent presentation the State Secretary himself expressed a wish to have the software and the model installed on his own PC!)

The earliest written critique of modelling methods which Forrester penned in 1956 (Forrester, 1956/2003) was primarily directed at tools for economic (not business) modelling. Maybe this work represents one manifestation of the vision he had nearly five decades ago.

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