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Applications of Linkages in Threshold 21: An Integrated Development Model

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Abstract

The Threshold 21 (T21) Integrated Development Model is a tool for exploring consequences of policy intervention through resource allocation on the long-term development goals of a nation. It's current version has 20 sectors, which can be classified into three groups: economic sectors (Industry, agriculture, services, technology, finance, military, government, rest of the world), social sectors (population, education, health care, nutrition, employment, income distribution, HIV/AIDS), and resource and environment sectors (energy, land, forest, water, air pollution). These sectors are dynamically linked to each other to form hundreds of feed-back loops. This paper highlights some of the linkages among key variables in T21 (including total fertility rate, life expectancy at birth, and cohort death rates), explains how these variables were quantified in equations, and discusses applications to a selected country, among the ten countries where T21 has been applied with funding from UN agencies, the World Bank, several national governments, and US foundations.

I. Introduction to T21 and its linkage overview

Threshold 21 (T21) integrates economic, social, environmental, and resources sectors in a single national development model, which provides national planners with an analytical tool to understand the complex interrelationships among these sectors and make decisions on where to invest available resources.

Using the concept of the World Bank's environment related indicators, the sectors in T21 can be classified into three types of capital around the production activity. These three capitals are Human Capital (population, education, health care, nutrition, employment, and income distribution), Natural Capital (energy, land, forest, water, and air), and Produced Capital (produced asset in production, social services, and government and private establishments)

The linkages among these three types of capital and the production activity are shown in Figure 1. Notice in Figure 1, linkages with <> around them are not yet implemented in the current version of T21. They are minerals and capital land demand.

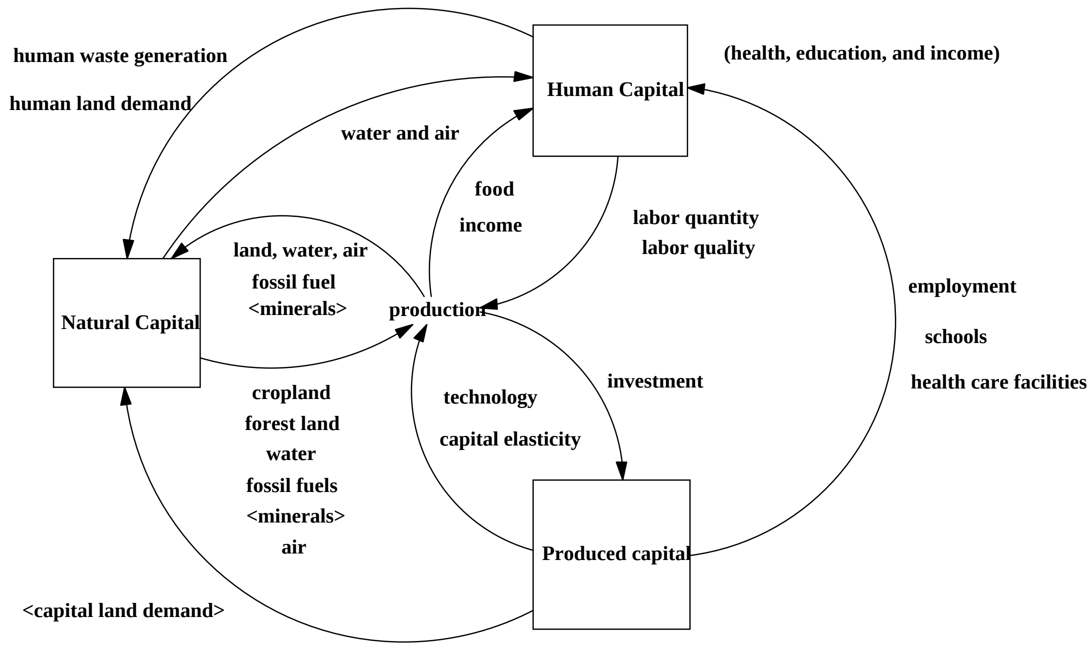

Figure 1: Overview of linkages in T21

Arrows in Figure 1 indicate the source (output from) and target (input to) of a linkage. For instance, the linkage in the top-left corner of Figure 1, human waste generation, is generated from human capital, and will affect natural capital.

Let us select human capital and examine linkages either pointing to it or originating from it.

Originating (output) from human capital are four linkages: human waste generation, human land demand, labor quantity, and labor quality. The first two linkages are not difficult to define. If we have a good population sector with age cohorts, and a good education sector which generates the indicator of average number of schooling years, and use this indicator to approximate labor quality, then the other two linkages can also be quantified.

The seven linkages pointing to (input into) human capital are water, air, food, income, employment, schools, and health care facilities. These linkages need to be further explored in order to understand how they affect human capital.

Human capital includes three sectors: population, education, and health care. The connection between these sectors is shown in Figure 2.

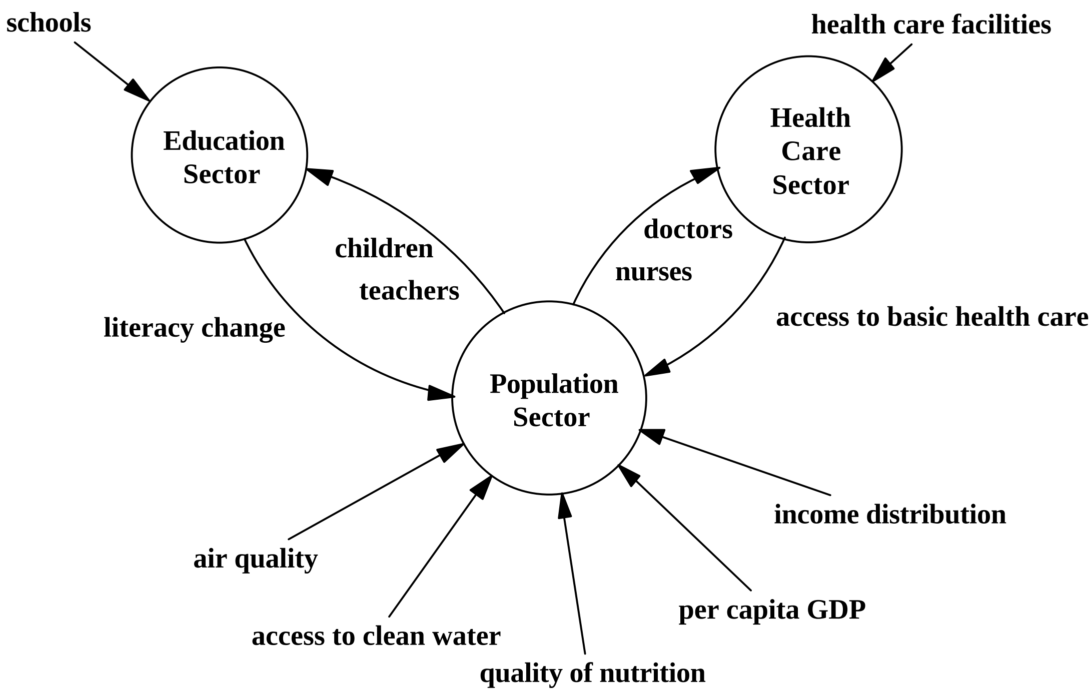

Figure 2: Linkages to the human capital

Of the three sectors, of population, education, and health care, it is obvious that the population sector has the most input linkages, and some of the linkages are not easy to quantify. So let us narrow focus on the population sector to continue our analysis.

II. The population sector and its input linkages

Figure 3 shows the population sector and all the linkages that affect it.

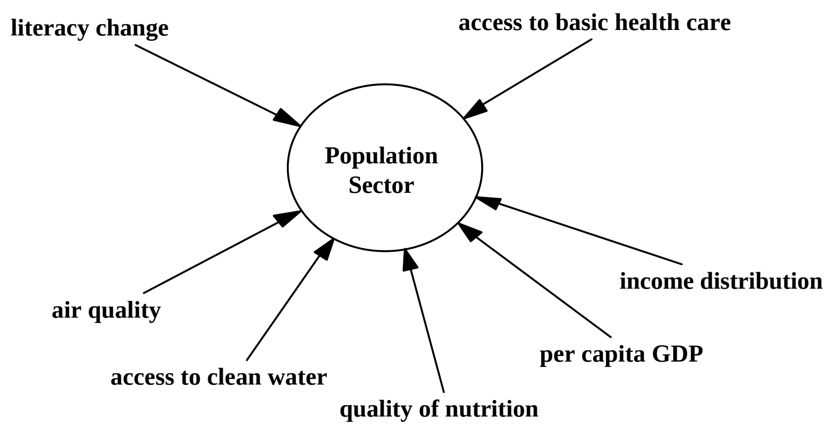

Figure 3: The population sector and its input linkages

The next question we want to address is: How do these linkages actually affect the population sector? A simple answer would be: They affect the births and deaths.

Figure 4 shows how each of the seven input linkages affects births and deaths. Four of them, income distribution, per capita GDP, literacy change, and access to basic health care, affect births, and all but literacy change affect cohort deaths. These linkages are based on our extensive research in demographic publications.

As income distribution is a new addition to T21, and its consequence on births and deaths is not yet fully studied, it will be omitted in the following discussion.

Our next step is to explore how births are being affected by the three linkages: per capita GDP, literacy change, and access to basic health care.

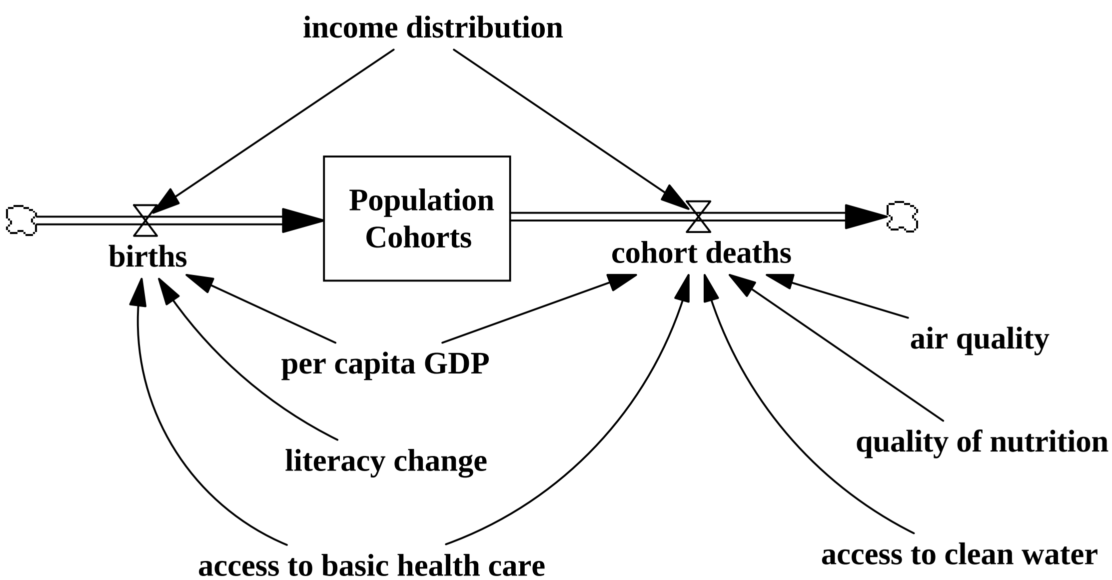

Figure 4: Births and deaths affected by linkages

III. Quantifying linkages to births.

To quantify the influence of these three linkages, we need to add several intermediate variables. The result is shown in Figure 5

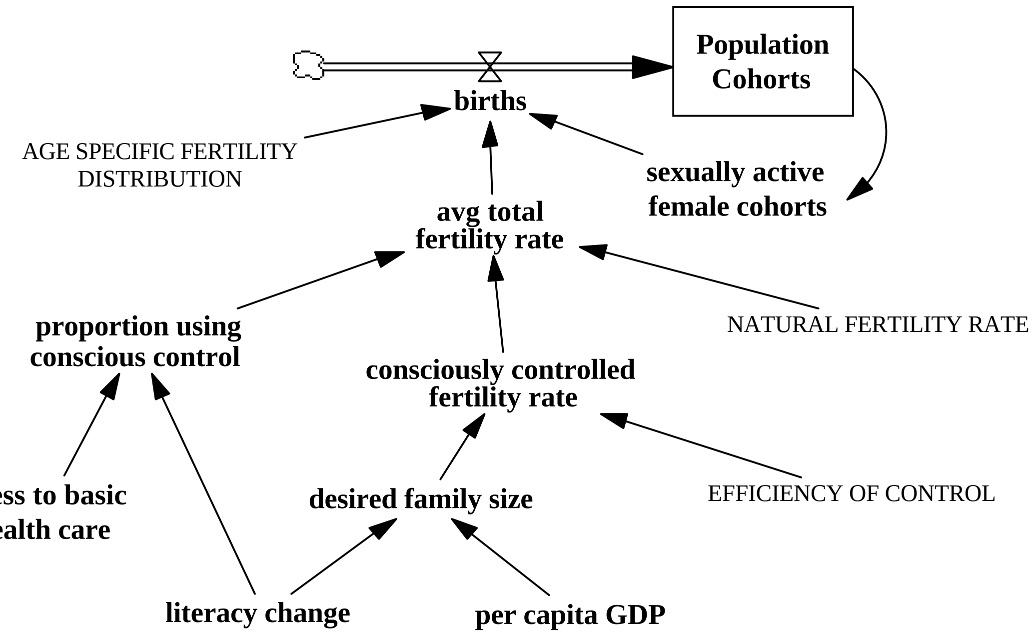

Figure 5: Births

Let us build equations from top down.

The equation for births is probably obvious:

Births =

sexually active female cohorts *
avg total fertility rate *
AGE SPECIFIC FERTILITY DISTRIBUTION

In which sexually active female cohorts come from population cohorts, and AGE SPECIFIC FERTILITY DISTRIBUTION is assumed exogenous. The only remaining variable to be defined is avg total fertility rate.

Avg total fertility rate is the weighted average of natural and controlled fertility rate, and the equation is:

avg total fertility rate =

consciously controlled fertility rate *
proportion using conscious control +
NATURAL FERTILITY RATE*
(1 - proportion using conscious control)

in which NATURAL FERTILITY RATE is assumed exogenous.

Consciously controlled fertility rate is related to two factors: desired family size, and how effective this desire is being achieved, so the equation is:

consciously controlled fertility rate =

desired family size * EFFICIENCY OF CONTROL

in which EFFICIENCY OF CONTROL is assumed exogenous.

Our research in demographic literature tells us that desired family size is closely related to the educational levels of both the husband and the wife, and to the economic status of the family, while proportion using conscious control is closely related to the educational level of the woman and the effectiveness of family planning programs. We use access to basic health care as a proxy for the effectiveness of family planning programs. Thus, the equations for the final two variables are:

desired family size =
f(average literacy rate of male and female, per capita GDP)

proportion using conscious control =
f(female literacy rate, access to basic health care)

IV. Quantifying linkages to deaths.

With our approach, we have already identified five linkages that will affect deaths: per capita GDP, access to basic health care, air quality, quality of nutrition, and access to clean water.

The difficulty in modeling the deaths of population cohorts is that there are as many death rates as age cohorts to be defined. In T21, there are 80 age cohorts for each gender, so a total of 160 death rates need to be defined.

The five linkages affect each of the 160 cohort death rates. How can we define all the 160 cohort death rates in a practical and sensible way? My answer to that question is “I don’t know”.

But by adding two intermediate variables, male life expectancy at birth and female life expectancy at birth, the problem becomes much more manageable. Figure 6 shows the diagram.

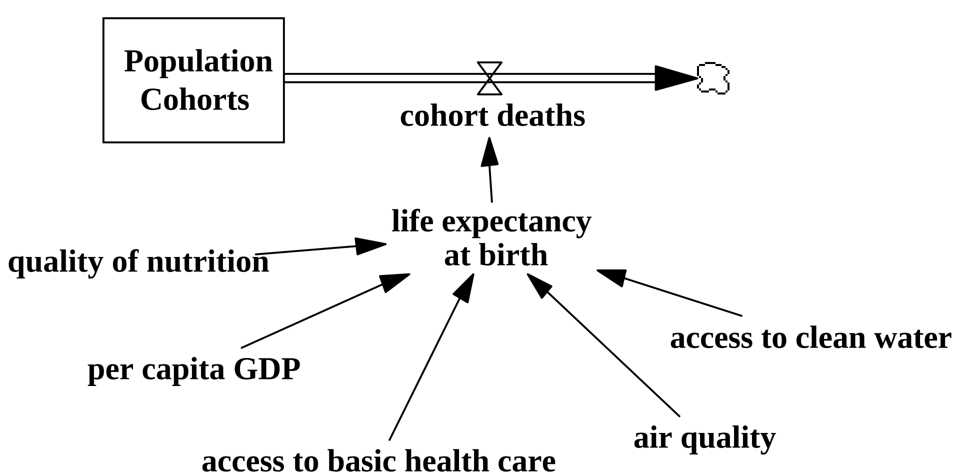

Figure 6: deaths

The equation for life expectancy at birth (with subscript gender) is first defined in relation to the five linkages as:

life expectancy at birth =
f(per capita GDP, access to basic health care, air quality,
quality of nutrition, access to clean water)

Once life expectancy is modeled correctly, we still need to define the relationship between cohort death rates and life expectancy. Luckily demographers have spent a lot of effort in that area and have come up with life tables which relate cohort death rates to life expectancy at birth for different mortality patterns of the world. We do not need to reinvent the wheel.

With the deterministic relationship between life expectancy at birth and cohort death rates, we complete our algorithm for cohort death rates.

But how accurate are these algorithms for births and deaths in real applications? We will discuss this topic in the next section.

V. Application Results

We have applied the above algorithms in our recent T21 models to three countries: USA, China, and Malawi. In all three cases, we achieved good fits between the model output and the existing population data from the United Nations and the World Bank for the period 1980 to 1996 (for the Bank's data) or 1997 (for data from UN)

We will use T21 for China to demonstrate. Results from T21 USA and T21 Malawi are similar.

Population data from UN includes five year age cohorts and total population; the data from the World Bank includes total fertility rate, life expectancy at birth, and total population. The total population from these two data sources for China are slightly different as the following figure (Figure 7) shows. And the difference can not be explained by the possible different times of the year when data were collected, because

1) both data series for total population show annual increases during 1980 to 1995, and
2) the total population from UN for 1990 was 1.1553 billion, larger than the Bank's total population for the next year (1991) of 1.1508 billion.

In calibrating T21, the population cohort data used is from UN, while the total fertility rate and life expectancy at birth are from the Bank. The slight difference among these two data sources could introduce error into T21.

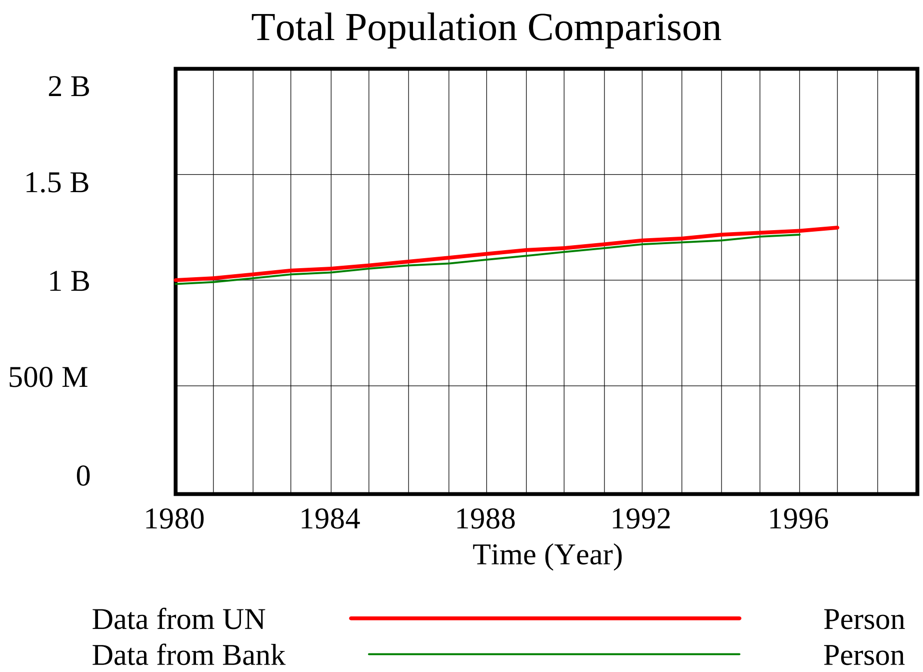

Figure 7: Data comparison between UN and the Bank

In developing the population sector we first made sure that the total fertility rate generated from T21 fits the data, as Figure 8 shows.

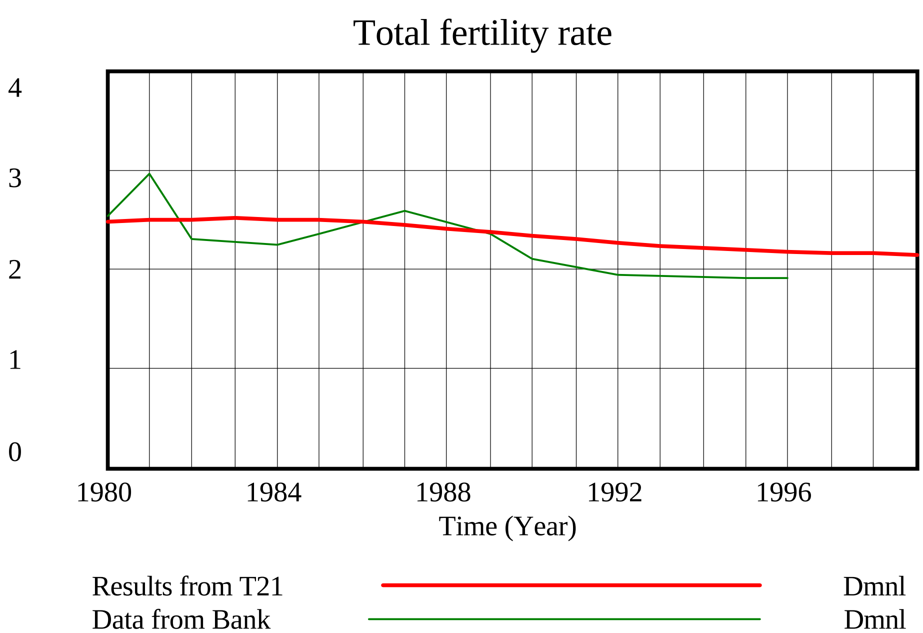

Figure 8: Total fertility comparison between T21 and data

The next step was to implement the algorithm for life expectancy to fit results from T21 to data from the World Bank, as Figure 9 shows.

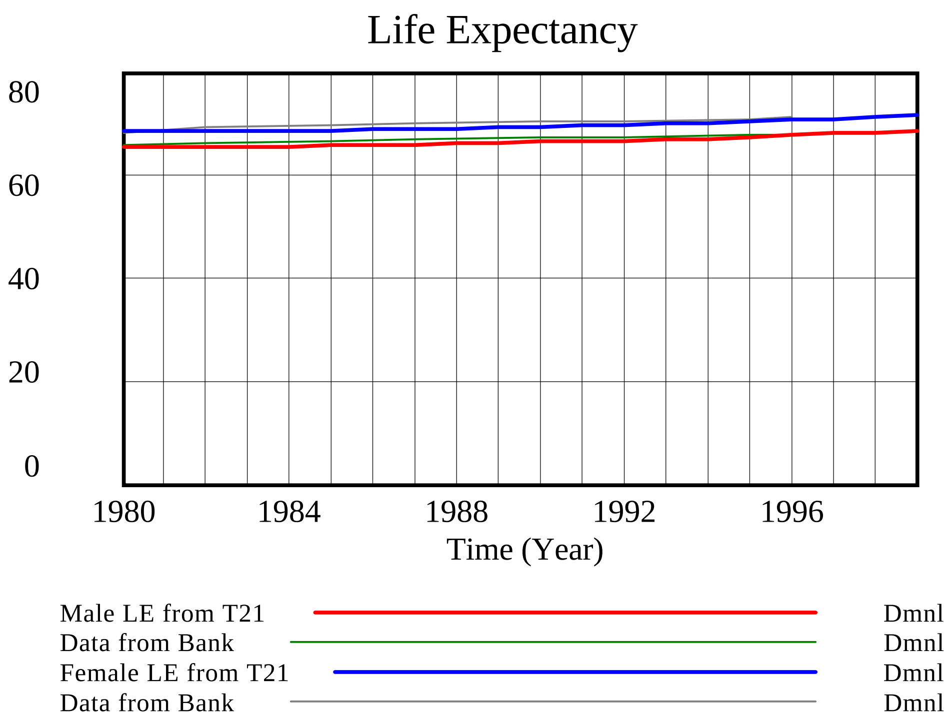

Figure 9: Life Expectancy comparison between T21 and data

There are 4 lines in Figure 9: two from T21 for male and female life expectancies, and two from data. As T21 results are so close to data, they become overlapped in the figure.

The same overlap happens to total population when comparing T21 generated results to UN data in Figure 10.

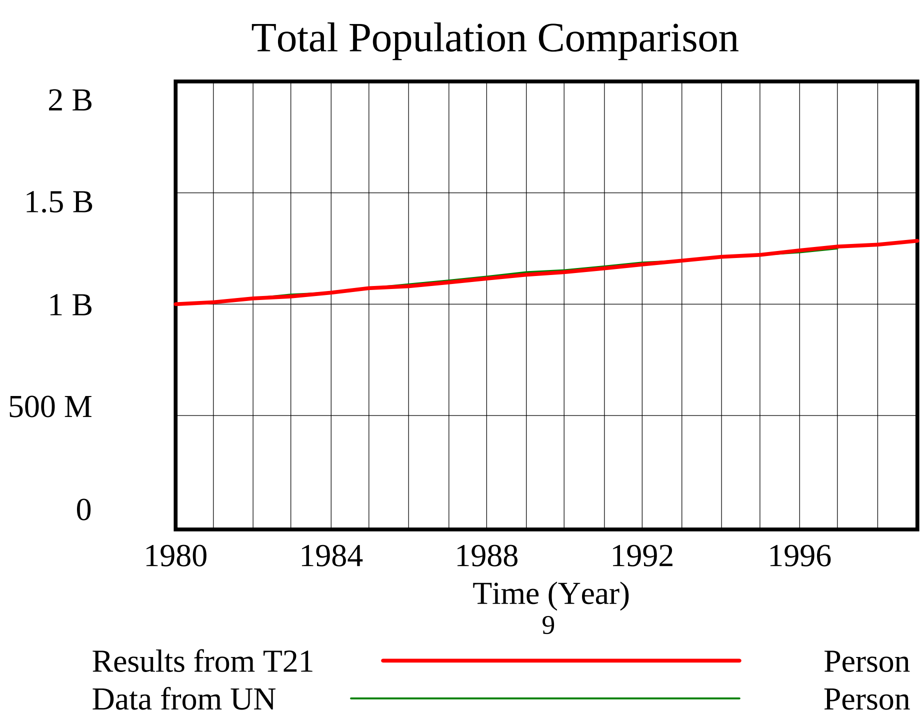

Figure 10: Total population comparison between T21 and UN data

As T21 has 80 age cohorts for each gender, you can pick any cohort to compare with existing data. Figure 11 used the age group 20 to 24 and compared T21 results to UN data. The fit was good as you see the overlapping was obvious.

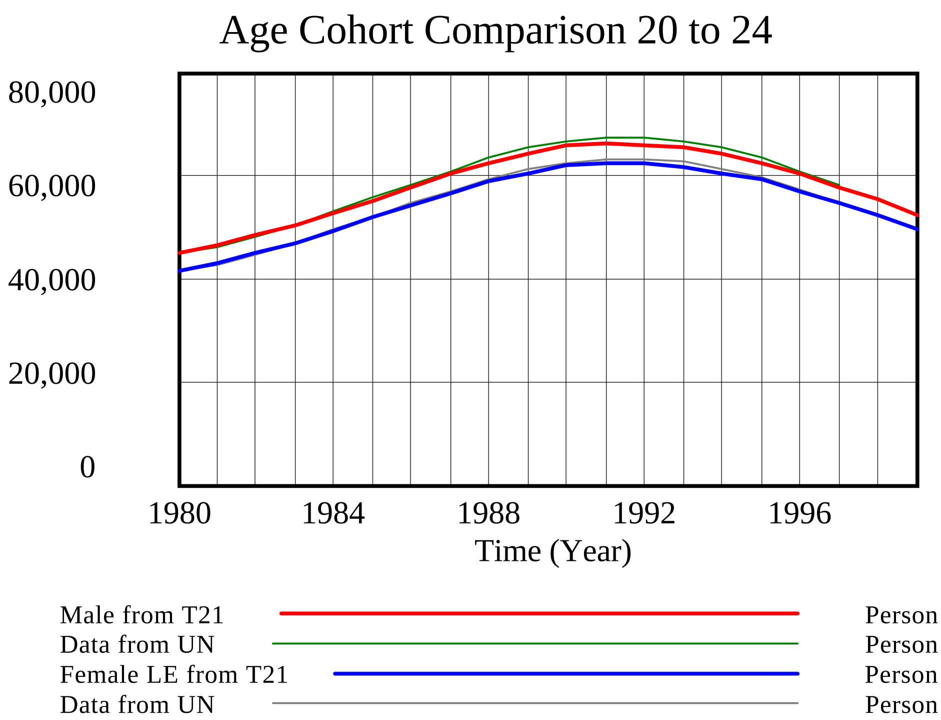

Figure 11: Age cohort comparison between T21 and data

VI. Summary

Linkages (or causal relationships) are vital in System Dynamics models. Identifying the right linkages is important in model formulation, but is only the first step. Next, it is necessary to develop specific algorithms that convert the conceptual linkages into actual equations. Finally, the task of fitting the model to actual data is essential for an applied model.

This paper reveals a few of the key algorithms implemented in the T21 model.

VII. References:

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