Is Immunization Demand Equal to Immunization Coverage?   A Case Study on Uganda Healthcare Provision

Abstract.

This paper critically examines the challenges associated with demand for immunization, including the interplay of political, social, economic and technology forces that influence the level of immunization coverage. In an earlier paper by the same authors, system dynamics modeling and case study research methods are used to capture the complex and dynamic nature of the immunization process. This paper suggests a framework to capture the complex and dynamic nature of the immunization process and tests its effectiveness using a case study on Uganda healthcare provision. The results indicate in cases of developing nations, immunization demand outstrips immunization coverage. The paper suggests that the model and results could be used for theory building in immunization policy evaluation in developing countries.

Keywords: System Dynamics, Case study, Immunization Coverage, Immunization Demand, Health care policy

1.   Introduction

Simulation modeling has become an important area for research strategy implementation and policy analysis for many application areas including health care management (Fone *et al.*, 2002; Eldabi *et al*., 2006, Homer and Hirsch, 2006; Edmunds *et al*., 2002; Grenfell and Anderson, 1989; Koelling and Schwandt, 2005; Subramanyam and Sekhar, 1987; Wolstenholme *et al.*, 2004).   Simulation modeling as a powerful method allows experimentation in a safe environment for testing new scenarios using "what if ?" analysis before deciding which changes, if any, need to be incorporated during policy formation. Computer simulation provide a simple yet powerful tool that can be used to model and understand complex systems from the macro systems level to the micro genetic level (Hethcote *et al*., 2004). The availability of a variety of simulation software has significantly expanded the role of simulation modeling in research, policy making and operational decisions (Fone *et al.*, 2002; Logan, 1998; McAleer *et al*., 1995).

Computer models are used extensively in many areas of systems management to provide insight into the working of a system. This is particularly useful when the system is complex and / or when experimentation is not possible. Due to increased pressure to reduce costs, increase efficiency and raise standards, health policy makers internationally have introduced a wide range of changes to healthcare in the quest for improved performance thus requiring System Dynamics techniques that have the ability to enhance the generation of knowledge in health services (Deakins, 2001). Homer and Hirsch (2006) state that system dynamics modeling in healthcare facilitates the incorporation of all the basic elements of a modern ecological approach, including disease outcomes, health and risk behaviors, environmental factors, and health-related resources and delivery systems.

Although system dynamics applications in health systems have been developed for almost 40 years, research has not been widely applied at the regional and national health systems level where integrated policies can be effectively modeled for dramatic health system improvements (Koelling and Schwandt, 2005). Although there are already other studies in the wider area of immunization coverage (Edmunds *et al.*, 2002; Grenfell and Anderson, 1989; Hethcote, 1997; Rohani *et al*., 1999; Subramanyam and Sekhar, 1987), System Dynamics based simulation modeling has not been widely applied to Immunization coverage investigation.

1.1 Definition of Key Concepts

This section defines some of the key concepts in this paper.

Immunization is defined as a process that increases an organism's reaction to antigen and therefore improves its ability to resist or overcome infection.
Immunization coverage is the proportion of the population or age group receiving a vaccine or a series of vaccines, compared to the total target population or total target age group (Guerin, 1998). The national service providers for immunization in Uganda compute the target population based on the average annual births.
Immunization demand is a sum of the new born infants and the backlog of immunization drop outs (whose parents actually demand for immunization).

2. Immunization Coverage

Increasing immunization coverage to prevent childhood diseases is an important developmental issue (Bryce *et al.*, 2003; DISH, 2002; WHO, 2002;1999) and an area of critical research (Bozette *et al.,*2003; Drain *et al*., 2003; Edmunds *et al*., 2002; Fairbrother *et al.*, 2000; Grenfell and Anderson, 1989; Hethcote, 1997; Stafford and Aggarwal, 1979; Subramanyam and Sekhar, 1987). Governments, donor agencies and projects have made a lot of contributions towards the improvement of immunization rates through the improvement of health infrastructure, financing, supplies, staffing and management of national immunization programs. Preventable childhood diseases such as measles and premature deaths still occur particularly in the developing countries due to low immunization coverage (WHO, 1999). According to WHO/UNICEF (2006), the global coverage for measles stands at 77 per cent, 28 million infants worldwide had not been vaccinated with DTP3 in 2005 with 75% of these belonging to developing countries.

Immunization coverage is lowest in poor countries and among poor populations such as Africa and Asia (Gwatkin, 2001). Globally, it was reported that the goal of fully immunizing 80% of the world's children was reached in 1990; however, coverage in Africa for that year was 55%. UNICEF/WHO (2005) further states that immunization coverage rose significantly since the launch of the Expanded Programme for Immunization in 1974 from less than 5% of the world's children in the first year to around 76% by the end of 2003. Many causes and solutions of poor immunization coverage have been suggested by various researchers (Borooah, 2003; DISH, 2002; Drain *et al*., 2003; Leask and McIntyre, 2003; WHO, 2002; Ymba, 2003) which clearly depict the complex nature of the immunization system thus the need to utilize System Dynamics (SD).

Stagnant and falling immunization rates in most sub-Saharan African countries has resulted into renewed international attention and ensuring that immunization programmes are effective and sustainable have become key issues of policy debate (IDS, 2006). In a study to evaluate new tendencies and strategies in international immunization, Martin and Marshall (2002) suggest that "*failure to immunize the world's children with life saving vaccines results in more than 3 million premature deaths annually*". Various approaches have been applied to understand immunization coverage problems, however, there are still acknowledged deficiencies in these approaches and this has given rise to research efforts for alternative solutions including the need to adopt new technologies to address the imbalance between immunization demand and coverage. The immunization system like many health care systems is very complex with many stakeholder (clients, doctors, nurses, managers, policy implementers) viewpoints that are difficult to manage. System dynamics provides us with tools which help to better understand difficult management problems such as faced by the immunization system in Uganda. In this research, SD modeling and case study research methods are applied at to capture the complex and dynamic nature of the immunization process, to enhance the understanding of the immunization health care problems and to generate insights that may increase the immunization coverage effectiveness. The application of System Dynamics was an attempt to provide decision making to immunization issues by understanding feedbacks, time delays and non linearity.

3. Sources of Problems in Immunization Strategy Implementation

Substantial evidence from the literature suggests the following as some of the most fundamental problems in immunization :-

- Low immunization coverage (UNICEF,2004; DISH II Project, 2002).
- Poor understanding of implication of immunization strategies and policy implementation (Hughart *et al*.,1999; Martin and Marshall,2002; Leask and McIntyre,2002).
- Poor provision and management of health care evidenced by inadequate planning, monitoring, and supervision at all levels results in inadequate immunization coverage among the hard-to-reach and high-risk populations in which infectious diseases is particularly high (Subramanyam and Sekhar, 1987; Drain *et al*.,2003).

4. Factors that influence immunization coverage

System archetypes show a simple representation of the underlying issues faced by management by providing a high level map of the dynamic processes (Senge, 1990). The dynamic processes presented in the immunization system can be explained using the "growth and underinvestment archetype" as illustrated in Figure 1.
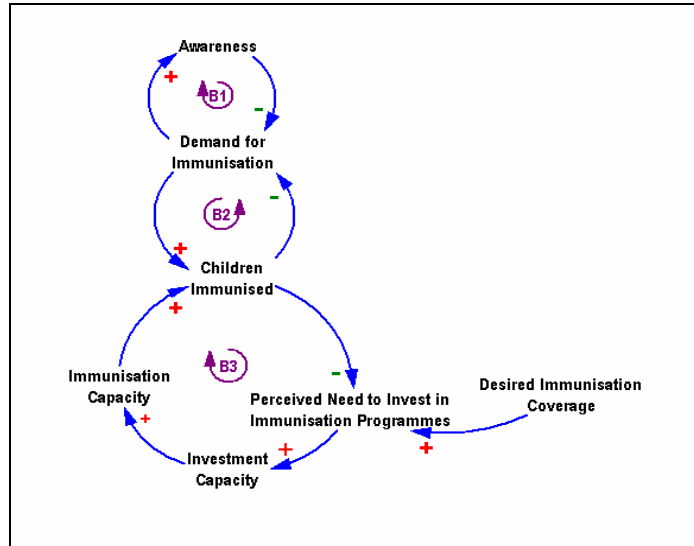
Figure 1: System Archetype explaining immunization demand and coverage

Policy makers and health professionals often assume that low demand or rumours reflect public ignorance of misinformation which needs to be corrected through education (IDS, 2006).   In order to increase the demand for immunization, governments finance immunization campaigns and advertise through various media. Growth in immunization programmes approach a limit, which can be eliminated or pushed into future programmes, governments invest additional capacity (ability to support health care personnel and acquisition of new vaccine technology and equipment).   However, government's investment in the immunization programmes must be aggressive and sufficiently rapid to forestall reduced demand. Often key immunization targets (desired immunization coverage) are lowered to justify underinvestment.

As illustrated in Figure 1, when lowered underinvestment targets are achieved, there is a self fulfilling prophecy where lower target goals lead to lower expectations, which are then born out by the poor immunization coverage caused by underinvestment.

Literature Review

Analysis of literature reveals how various social, economic and geographic factors influence people's access to health services which in turn influences immunization coverage. Some of the factors that have been suggested by other researchers are shown in Table 1.

Table 1 . Key variables associated with immunization coverage

No.	Variable	Associated with	References
1.	Immunization Demand	- Religion /Caste - Number of Children in household - Mothers age - Use of public service providers, multiple vaccination providers - Availability and time of vaccination Service - Strength of social organization (community mobilization - Mother's level of literacy, awareness on vaccination issues (dosage), motivation, busy schedule, social stability (single/married), fear of side effects and family problems - Area of residence (urban /rural) - Country's level of poverty,	Borooah, (2003). Bryce *et al.* (2003). Ymba(2003). Maani and Stephenson (2000). Edmunds *et al*. (2002). DISH II Project (2002). Drain *et al.*(2003). LeBaron *et al.* (2001). Hughart *et al.* (1999). Martin and Marshall (2002). Hall *et al.* (2002). McIntosh and Paradiso, (2002).
2.	Coverage of Child survival interventions	- Training of health workers which should include which includes clinical practice and sufficient facilitators - Use of materials relevant to local culture and language - Training of H/Workers in the management of common diseases - Tailored supervision in frequency and content to needs of the workers - Assessment of patients to determine - Regular monitoring activities such as supervision - Relevant data at sub-national levels (collection & analysis) - Effective Interventions to be implemented at community & health facility levels - Assessment of alternative delivery strategies - Supplies must be tailored to meet demand and respond to the needs - Strengthening of national health systems which includes : Manpower, drug and vaccine management and supply, information systems, functional referral, child health programmes and simplified technologies such as pre-packed single doses injection devices.	Bryce *et al.* (2003). Edmunds *et al*. (2002). Leask and McIntyre (2002). Lansley and Bedford (2002).
3	Immunization Coverage	- Healthcare system (organization of vaccines, supplies etc.) - Cost of immunization - Inadequate financing for social mobilization - Inability to provide feedback to media queries - Belief in myths (HIV, anti-fertility drugs) - People tired of National Immunization Days - Poor sensitization - Superstitions and suspicions - Government politics - Lack of trained vaccinators (parents question their skill)	UNICEF (2004).

5.   Methodology

The study employed the Dynamic Synthesis Methodology (DSM) as suggested by Williams(2000). DSM combines two powerful research strategies namely :- the case study research method (Galliers, 1984; Mason and Mitroff,1973; Yin, 1984) and the System Dynamics Modeling (Forrester, 1961; Richardson and Pugh, 1981; Sterman, 2000) techniques. Case studies are used to validate System Dynamic models and provide a deeper understanding of the problem being investigated.

Combining System Dynamics and case study research methods increases the robustness of results and the findings as well as strengthens through cross validation case study results. DSM uses a six stage approach shown in Figure 2.
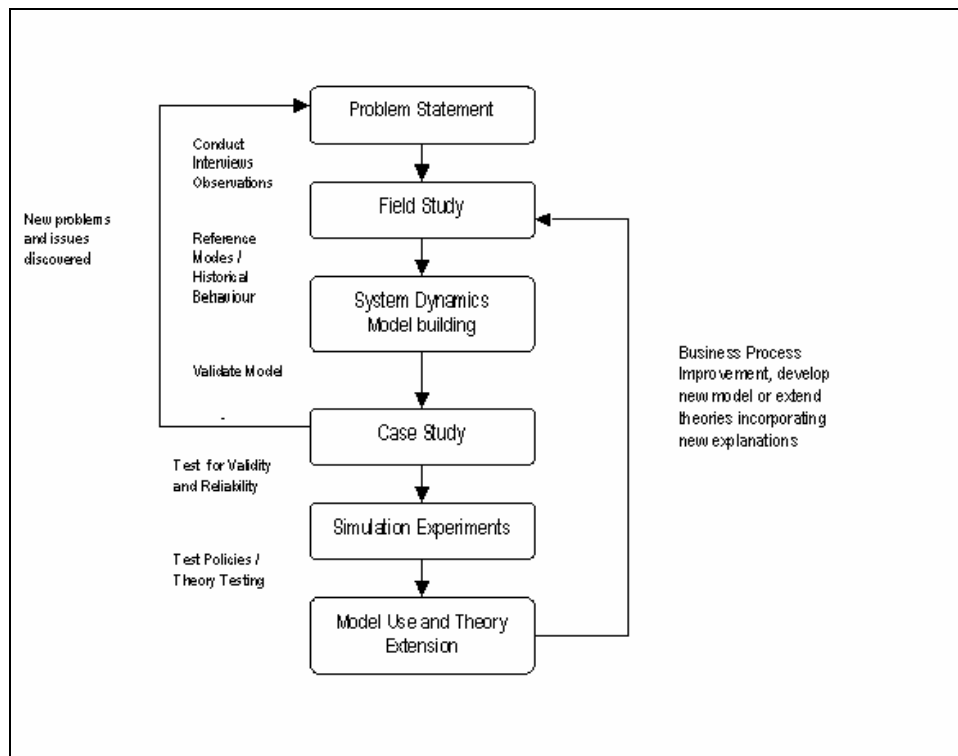

Figure 2 : The Dynamic Synthesis Methodology (Williams, 2000)

Combining simulation and case study methods as proposed by the Dynamic Synthesis Methodology is beneficial in that the strength of the case study enables the collection of data in its natural setting. Case study enables the collection of on-site information of the current system, owners and user requirements and specifications used to develop the generic model. To this moment, DSM has been a university based research effort, but has not been tested whether it can be applied to case study problems in healthcare. Several case studies have not been conducted to validate DSM and to use the resulting insights to transform it as a practice based methodology.

6. Case Study : Ugandan Immunization System

Field Studies

Field studies with the main objective of studying the factors associated with the provision and utilization of immunization services were carried out. The study was analytical; involving the various stakeholders who are important as far as the immunization system is concerned. Field studies were conducted in the months of October 2005 – January 2006 in a semi-urban district with the aim of determining how best to capture and analyse the full range of activities and events that are associated with immunization coverage. A better understanding of the research problem required the use of both qualitative and quantitative methods from the particular case. Interviews with parents and other family members explored their

knowledge, beliefs and attitudes towards vaccination and health workers and other social issues surrounding their response towards immunization. Interviews with health workers explored the challenges that are faced in the provision of healthcare services particularly in immunization. Interviews with local leaders explored issues relating to community mobilisation and response to immunization. Preliminary results from the study were presented and discussed with both the community and district health authorities. Secondary data emanating from the study (survey), interviews with the stake holders of the immunization process, field observation of some activities and also other sources of data especially those that would be able to highlight the historical, social, political and economic context were used.

Case Study

Results from field studies indicate a very intricate Ugandan immunization system. Health care services in Uganda including immunization services are provided through a decentralized system consisting of geographically spread health centres, regional hospitals which are categorized into health districts and health sub-districts. Policy design and review, strategic planning, establishment regulations, monitoring and evaluation and disease surveillance are carried out at the national level. The development of health plans and service delivery are channeled from the national level through the district, health sub-district and community-based health centres. Each health centre has its own immunization schedule and plan with hardly any collaboration with the different health centres / hospitals offering immunization services.

In a resource constrained economy like Uganda, the responsibilities for planning, resource mobilization and allocation, management immunization services, storage and distribution of vaccines, supplies and equipment to the units under their supervision, maintenance of cold chain and training are done at the district and sub-district level. The district is responsible for support supervision, surveillance, management of outbreaks, development of training materials, social mobilization and advocacy. Vaccine importation is done at the national level from approved sources based on accepted standards and national procurement procedures. The distribution of vaccines is done through the cold chain system which comprises of various processes namely: receiving, transporting, storing and distributing of vaccines from the manufacturers to the central, district and vaccine stores, hospital and other health facility static units and outreaches. In an effort to minimize vaccine wastage, districts forecast requirements of vaccines, equipment and supplies based on target catchments and target population.

Figure 3 shows the subsystems and key stakeholders in the immunization system, their roles and responsibilities.
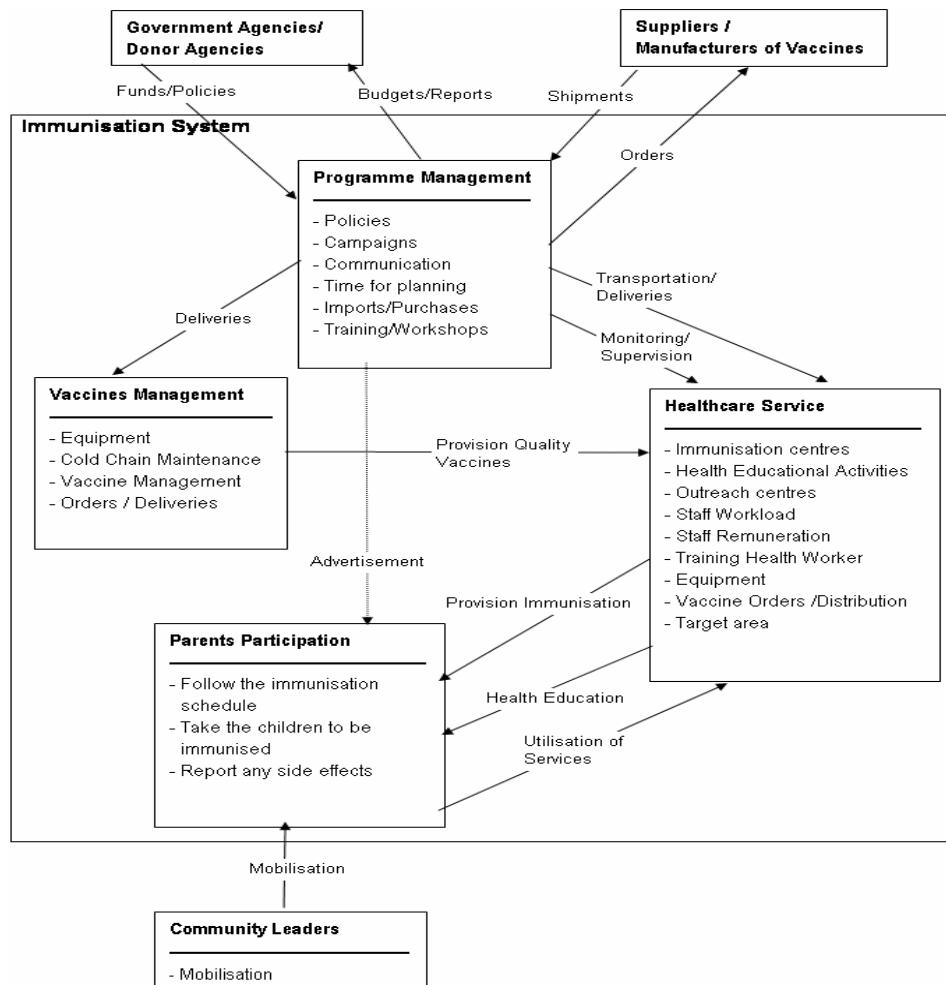

Figure 3 : The Ugandan Immunization System

Results from the Case Study

Immunization coverage focuses on the supply and delivery of immunization services, while immunization demand is reflected through the parent's acceptance and the child's attendance according to the immunization schedule. Demand is an interplay of factors arising from the supply of immunization services (healthcare factors) as well as population characteristics (socio-economic factors and background factors).

Healthcare factors associated with the supply of immunization services cause the parents to develop trust in the healthcare system as well as increase awareness and knowledge as far as immunization issues are concerned as shown by the two reinforcing loops in Figure 4. Loop R1 shows that an increase in health centre attendance attracts more financial and logistical support from the central distribution. Increased support results availability of transport, well maintained equipment, availability of vaccines and motivation of health workers which improves health

service delivery (reduced waiting time for mothers, more time to explain immunization issues to the mothers, reliability of immunization services, health worker attitudes) which in turn will increase health centre attendance. Loop R2 on the other hand shows that the more parents attend health centres, then they are acquire more knowledge through educational activities carried during immunization sessions.
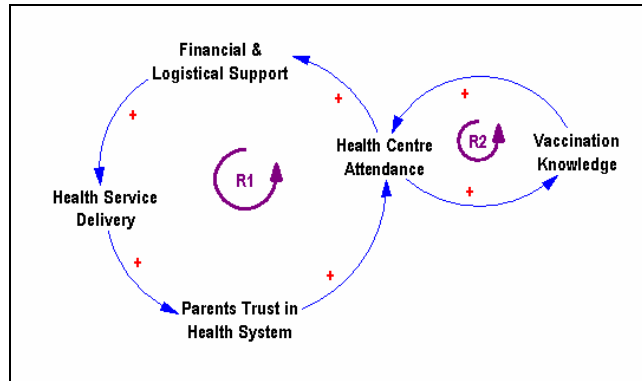

Figure 4 : Influence diagram showing healthcare factors

Parental factors that might affect the parent's willingness to respond towards immunization uptake result from the background and socio-economic situation of the parents. These include literacy levels, beliefs (myths), level of trust in the health system, level of awareness of immunization issues and social economic issues (stability of family, busy work schedules for mothers and poverty level).

Community factors arising from the community where the children to be immunized live. These include civil unrest, regional poverty, sources of immunization information, communication channels, availability of infrastructure and community support from leaders.

The Model

The model of the problems / issues associated with immunization was constructed based on the influence diagrams which were constructed in the problem identification stage. Three sectors (population, parents and immunization) are used to explain the relationship between immunization demand and coverage. Simulations of the model are run for 15 years 1990-2005.

Population Ageing Sector

The population ageing sector has four stocks which represent the four different age groups namely infants (below 1 year), children (1-14), reproductive age group (15-49) and adults above 50. Infants (below 1 year) are particularly separated from the children because this is the age group that when immunizations are carried out and therefore represents the population that receives immunization. Births are based on the number of women of child bearing age (reproductive population, female fraction), average fertility rate, infant mortality rate and mortality rate of the different age groups. The population sector shows the dynamics that are involved in the population growth.

Figures 5,6 and 7 below show the graphical data that is used to populate the model for the period 1990 – 2005 (UBOS,2001;).
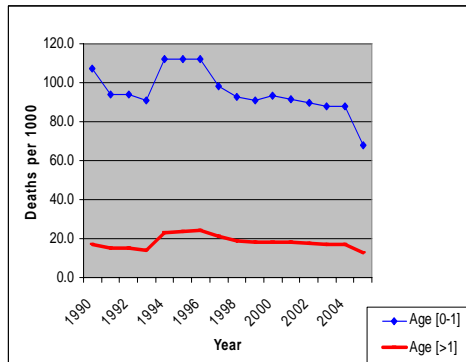

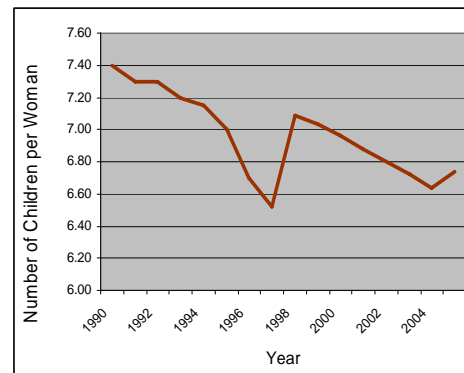Figure 5: Uganda Death Rates 1990–2005

Figure 6: Uganda Fertility Rates 1990-2005

The infant mortality rate in Uganda is high due to a number of diseases. Some of the major causes of infant deaths include Respiratory Tract Infection (RTI) (18%), diarrhea(15%), malaria(12%), measles(10%), and HIV (12.5%). The infant mortality rate is separated from the death rate of the rest of the population. The infant population decreases in the first 4 years due to the increased high infant mortality rate. There is a sharp decrease in the child population in the 5th year resulting from the infant deaths that occurred in the previous years. These are attributed to low immunization coverage which was experienced in the early 1990s. In 1993, the Uganda Expanded Programme for Immunization was launched and the immunization activities were revived.   The infant population represents the demand for immunization. Figure 6 shows the average fertility rate for Uganda (UNFPA, 2006).
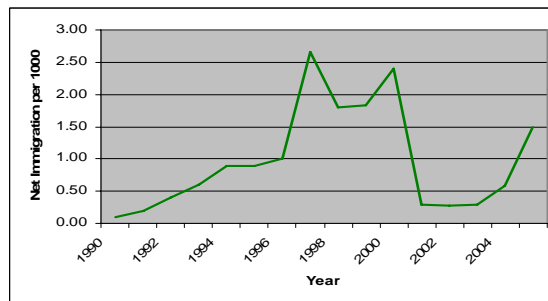

Figure 7: Uganda Net Immigration Rates 1990–2005

Figure 7 shows the net immigration rate for 1990-2005. The high peaks in the graph represent the migrations from the neighboring countries (Rwanda, Republic of Congo, Sudan, Burundi) due to civil wars. Table 2 below shows the initial stocks of the different population categories in 1990 (UBOS, 2005)

Table 2: Initial stock values of the population by Age (in thousands) for the year 1990

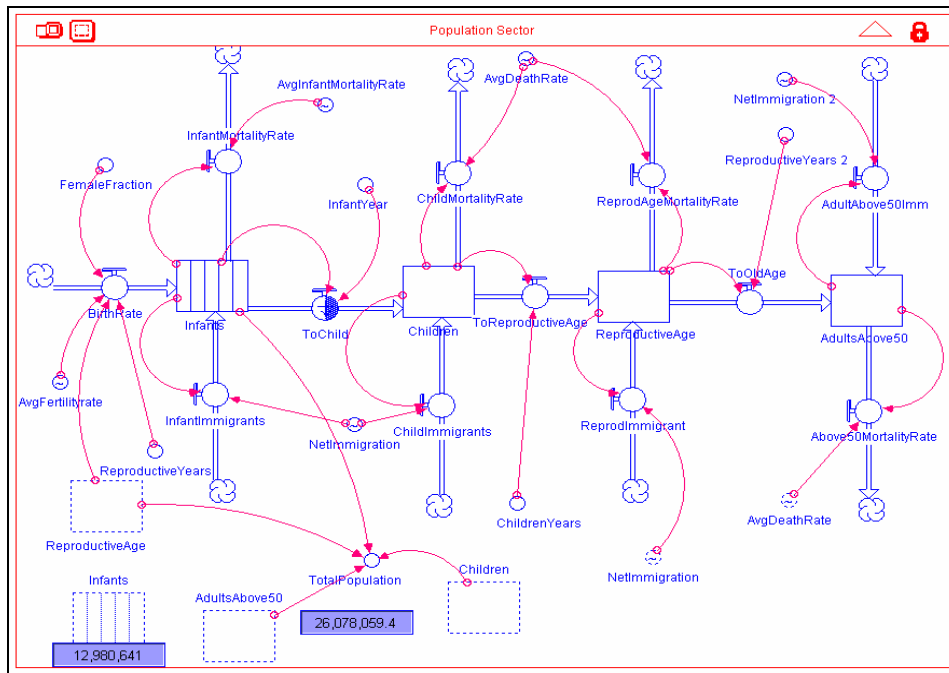|	**Infants**	**Children**	**Reproductive**	**Adults (50+)**
Initial value	933,935	8,225,798	7,184,104	1,616,423

Figure 8 : Population Ageing Sector

Parents Sector

Figure 9, shows the key factors that are associated with the parent's response to immunization. One of the key drivers of parents' response is immunization awareness (importance of immunization, diseases, vaccines, immunization schedule). Various forms of advertising are used to sensitise the communities in order to counteract the awareness which may arise due to myths. Other key issues associated with participation are parents' trust in the health system and socio-economic effects.
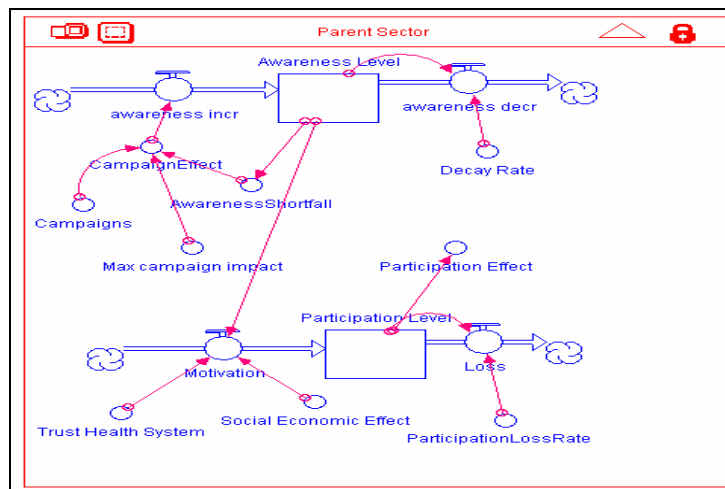

Figure 9 : Parent Participation Sector

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Immunization Sector

Figure 10, shows the factors that are associated with immunization coverage. The stocks represented here are immunized children, drop outs (children who do not complete their immunization schedule), effectiveness of health centres, health workers and immunization awareness. Immunization demand is a sum of the new born infants and the backlog of immunization drop outs.   Immunization coverage is the fraction of the immunized children out of the total number of infants.
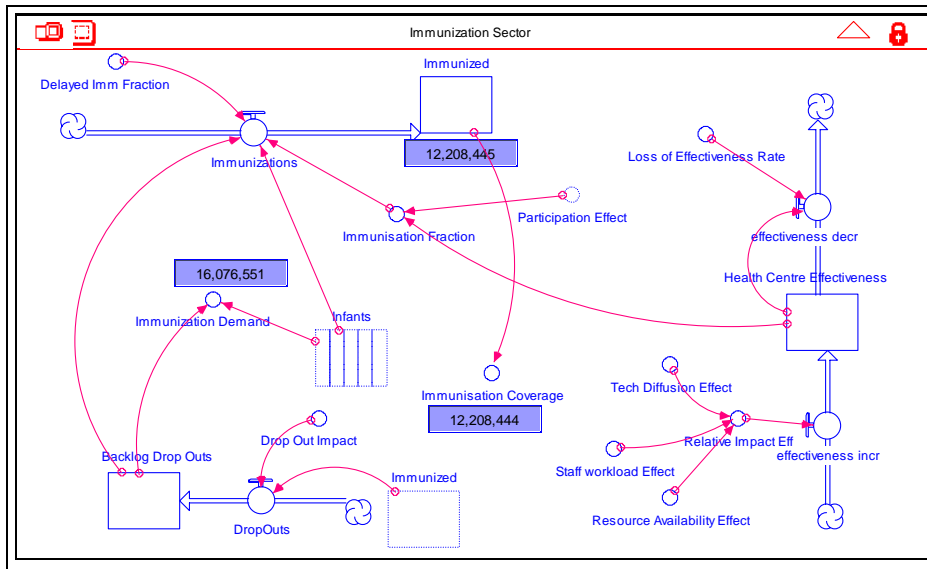

Figure 10 : Immunization Sector

Results of Model Runs

Figure 11, shows the model runs for parents participation level, campaigns advertising and awareness level. The level of participation is rated on a scale of 0-1 while awareness level is rated on a scale of 0-0.1. Vigorous campaigns and advertising are done only after 5 year period.
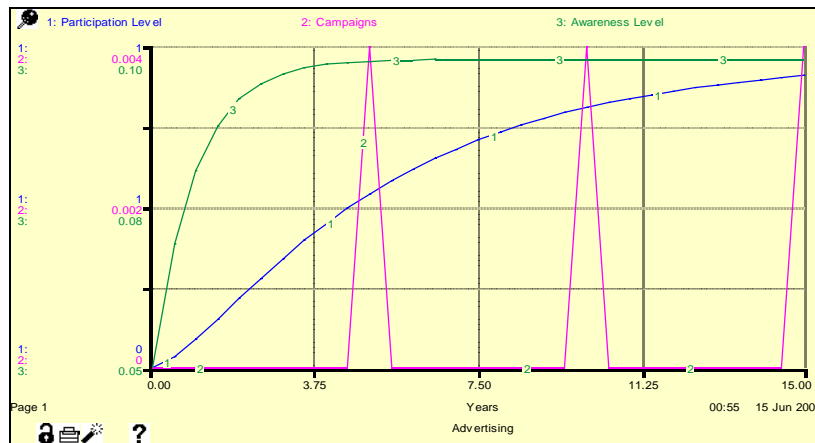

Figure 11. Participation, campaigns and awareness

Figure 13, shows the backlog of drop outs (infants who start but do not complete immunization), immunization demand and coverage. and how the number of drop outs increases each year. As the parents' participation level increases the number of children immunized increases with the same trend.
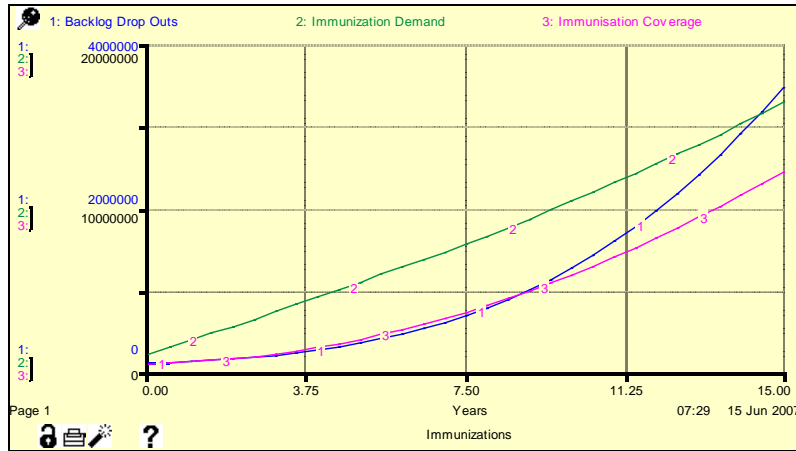

Figure 12. Immunization demand and coverage

Further simulation runs with decreased and increased participation are shown in figures 13 and 14 respectively. Increased participation results in increased demand and decreased participation shows a decreased in immunisation demand as well. In the three simulation runs of the model, immunization demand far exceeds the infants who are covered by immunization programs.
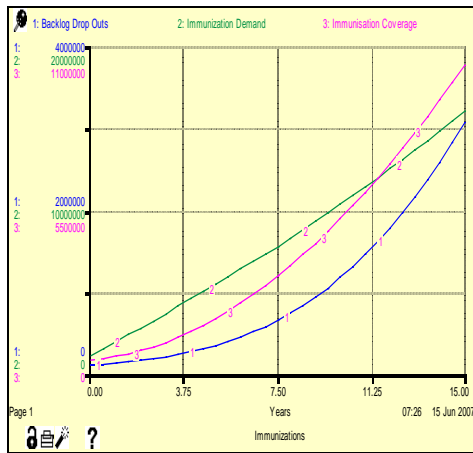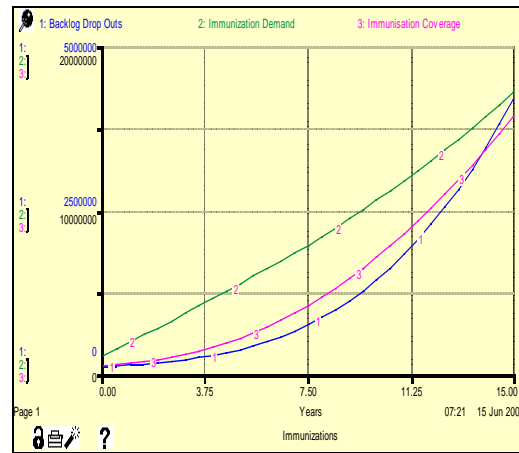

Figure 13. Decreased participation

Figure 14 : Increased participation

7.   Discussion of Results

The model shows a simplified representation of variables in the immunization system. Immunization coverage targets are set based on the average annual births. The model shows that population dynamics such as the rate of immigrants and backlog of drop outs affects the population that has not received vaccines thus increasing the demand. There is need to cater for immigrants and backlog of drop outs when planning for national immunization programmes. As the number of drops outs increases each year,

there is need to intensify immunization programmes that specifically target them which can boost the herd immunity and in turn reduce the occurrences of epidemics. In addition to immunization campaigns, aavailability and accessibility of health services, there are issues that affect the adoption and diffusion such as literacy levels, cultural backgrounds – myths, beliefs, socio-economic status of households, poverty levels and level of civil unrest that need to be addressed nationally for immunization coverage to improve.

The model helps to generate insight to policy development as far as immunization and healthcare is concerned and generates deeper insight of the issues that are associated with immunization coverage.

8.   Conclusion and Future Work

The model shows that immunization demand is far beyond immunization coverage. The study validates, empirically and theoretically that there is need to improve immunization coverage to meet the demand. Future work involves further expansion of the model to allow increased empirical space of the problem to enable better generalization of the results in developing countries.

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