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Modeling the dynamics of maternal healthcare in Uganda: a system dynamics approach

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Abstract. This paper critically examines the challenges linked with maternal healthcare and their interactions with political, social, economic and technological forces. Various interventions have been employed to comprehend maternal healthcare problems in developing countries, however, there are still acknowledged deficiencies in these interventions. The System Dynamics methodology was employed to capture the complex and dynamic nature of maternal healthcare in Uganda with the aim of understanding the problems towards improved decision making. A descriptive framework showing the variables, relationships and feedback loops involved in maternal health demand and healthcare service provision was developed. The framework provides insight into the system thus enhancing the decision making process and the development of relevant health information systems which could substantially improve maternal healthcare demand and the effectiveness of the health system.

Keywords: modeling, system dynamics, maternal healthcare, developing countries

1 Introduction

Almost 99% of the maternal deaths in the world over, occur in low and middle income countries (LMIC), yet most research is focused on the 1% deaths that arise in high income countries[11]. LMICs are grappling with astronomical increases in health care costs and severe pressure at the same time to provide improved quality of care for their patients with limited resources[10]. The pressure on the health care managers has been compounded by the UN declaration call for a 75% reduction in maternal mortality between 1990 and 2015. According to the WHO report of 2003, this call led a number of countries to focus on the capacity of health care systems so as to provide adequate and timely services[19]. Countries the world over, have strived to effect significant reductions in maternal mortality through:
(1) narrowing disparities within countries between socio-economic, geographical and ethnic groups,
(2) expansion of maternal and child health services in the context of primary care,
(3) increased emphasis to the management of high risk pregnancies,
(4) provision of information on reproductive health services including family planning services,
(5) dealing with the health impact of unsafe abortion and reducing the recourse to abortion and
(6) meeting nutritional needs of child bearing women.

A national study conducted at 97 health facilities in Uganda, including 30 hospitals, found the institutional Maternal Mortality Rate (MMR) to be as high as 846 per 100,000 live births[16]. It is conceivable, therefore, that institutional mortality rates would even be higher than national averages. The prevailing high fertility rates of 6.9 births per mother, in an environment with poor access to quality maternal health care, has continued to put the health of Ugandan mothers and their infants in jeopardy[17], with an estimated 1 woman in 25 dying from maternal causes in Uganda (the lifetime risk)[19]. Lack of human resources of health care

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has been identified as a major limiting factor in implementing health policies which could avert this danger in the developing world [1]. Uganda, with a dismal 6 nurses to 100,000 population is among the countries which have declared herself to be facing nursing shortage and is therefore in need of additional nurses[18].

Fig. 1 below shows the dynamic pattern/ Behaviour over Time (BOT) of the Ugandan maternal mortality rate for a period of about 20 years which requires to be managed or controlled. These patterns are often by BOT graphs, popularly known as reference modes. These are system thinking tools used to highlight important insights into the underlying dynamics present in a system[14]. The BOT of the dynamic variables demonstrate how problems come into existence and how they are likely to manifest in the future[25]. Some of the dynamic patterns in health care system that need to be understood and therefore need to be managed well are population and maternal mortality rate. Fig. 1 reveals a decline in MMR for the last 20 years from 523 to 435 deaths per 100,000 women. It is clear that the decline has been very slow and therefore presents an urgent need to explore the challenges of maternal health in order to further lower the rates to minimal levels.

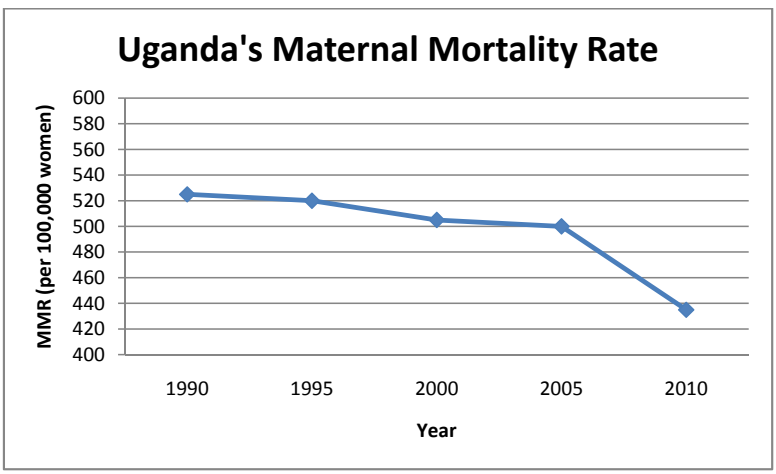

Fig. 1. Maternal mortality rate (the data is based on UDHS (2000/01))

The Ugandan population has grown exponentially from 16.5 million in 1990 to about 30 million in 2010. As the population increases, the number of mothers also increases which in turn increases the demand for maternal health care services. An increase in the number of mothers without a proportionate increase in maternal health services especially skilled attendance at birth leads to more maternal deaths. This trend can also be accrued to the short time spacing between births by mothers in the country. On average a mother in Uganda gives birth to two children in three years, a phenomenon which enhances the maternal health risk of mothers and consequently maternal mortality increases[18]. The increase in the mothers' population exerts pressure on the health sector, leading to an increase in the demand for reproductive and maternal health funding. However, the response to this demand is gradual and can be substantially realized over a long period of time.

Various approaches and interventions that are geared towards the improvement of maternal healthcare have been employed through the definition of the essential safe motherhood packages which include: antenatal care, safe delivery, post-natal care, emergency obstetric services such as caesarian section and incomplete abortions, prevention and treatment of infections in pregnancy including sexually transmitted infections, information and counseling on human sexuality and responsible parenthood and prevention and treatment of infertility. The various methods employed use linear approaches which do not capture the dynamics and delays in the complex healthcare systems. Although various interventions have been employed towards the improvement of maternal healthcare, maternal mortality has remained obstinate in LMICS, with Uganda being listed as one of the eight countries with the highest maternal mortality rates in the world[21].

There is therefore need, to employ System Dynamics modeling which has not been applied in maternal health care in Uganda yet provides a holistic approach that enhances understanding of maternal health issues

for better policy making since simulation. System Dynamics has potent tools that are used to enhance the understanding of complex systems of non-linear type. The main objective of this research was to develop a better understanding of the intricacies associated with maternal healthcare by employing the System Dynamics methodology for improved decision making. This paper defines key concepts (Section 1.1), introduces the various methods employed in the study of maternal healthcare (Section 1.2), describes the methodology employed in this research (Section 2), the descriptive framework (Section 3) and insights generated from the framework (Section 4).

1.1 Definition of key concepts

Maternal health refers to the health of mothers and their children, usually 0 - 5 years. Maternal health is usually discussed in terms of safe motherhood, which refers to the means of ensuring that all women of child bearing age receive the care they need to be safe and healthy through pregnancy and at child birth[20].

Maternal health quality is the degree to which health care services for mothers and their young ones increase the likelihood of desired health outcomes in other words it is concerned with interventions that save lives of mothers from deaths related to child birth.

Maternal mortality is the death of a woman of child bearing age while pregnant or within 42 days of termination of pregnancy irrespective of the duration and site of the pregnancy, from any cause related to or aggregated by the pregnancy or its management but not from accidental causes[20].

1.2 Methods employed in the study of maternal healthcare

This section reviews literature on the methods that have been employed in the study of maternal healthcare. This study found out that a number of studies in maternal healthcare have utilized statistical methods to establish factors and recommendations towards the improvement of maternal healthcare. Some of the studies that are relevant to this study have been discussed below.

Fort et al. [9] employed surveys and multi-variate analysis in a study aimed at investigating the factors affecting the performance of primary reproductive health providers (nurse-midwives) in maternal healthcare in low-resource settings. A performance improvement model with five key factors (job expectations, performance feedback, environment and tools, motivation and incentives, and knowledge and skills) believed to influence performance outcomes was used. The study involved observation and interviews of nurses and midwives involved in conducting real or simulated antenatal and postpartum/neonatal care services. Multiple regression analyses were conducted with the merged datasets to obtain the best models of ”predictors” of performance within each clinical service. This study revealed that the antenatal and postpartum care performance of health providers in Armenia is strongly associated with having the practical knowledge and skills, receiving recognition for their work as well as having performance feedback.

Bollinger et al. [2] used simulation modeling to improve the understanding of changes in maternal health services and how they could possibly avoid maternal deaths. A simulation model was developed to show how changes in the Maternal and Neonatal Program Effort Index (MNPI) item scores would affect the MMR. The model has been used in the western world to prioritize a series of interventions that produce the greatest impact on MMR such as estimating the cost of implementing maternal and newborn health interventions. Although the model has also been used as an evaluation and planning tool to inform the planning process at various levels on priority interventions, this research was set to improve maternal healthcare by employing a holistic approach where all stakeholders would be employed.

Brown et al. [3] carried out a study to review maternity services in Australia. Data was collected from post natal mothers, analysed using a logistic regression model. The findings revealed the following factors as being highly related to dissatisfaction with intrapartum care: lack of involvement in decision making, insufficient information, a higher score for obstetric intervention, and perception that caregivers were unhelpful.

The studies above demonstrate that statistical methods have been employed in maternal healthcare and have been used to support management decision making process, however, they focus on isolated aspects of maternal health. This study therefore, employed the System Dynamics methodology in order to capture the diverse stakeholder viewpoints as far as maternal healthcare is concerned.

1.3 Applications of system dynamics modeling in healthcare

System Dynamics qualitative models utilize tools which provide information giving a greater understanding of the problems being investigated, thereby enhancing managers' abilities to make informed decisions. Fone et al., [8] and Logan [12], contend that since the 1970s, innovative researchers have used simulation modeling techniques such as SD to better understand some of the toughest problems that health care managers face. Research shows that some of these problems are intractable to comprehend using conventional epidemiological research methods[25]. System Dynamics (SD) modeling has become a popular and effective decision-making tool for health care managers. Some of the applications of System Dynamics modeling in healthcare include; immunization coverage[24], epidemics[6, 7], disease management[15, 26]), supply and demand of human resources for health[12], health planning and chronic illnesses[13]. Dangerfield et al. [5] used simulation and modeling to quantify the effects of different prevention and treatment policisies in HIV/AIDS. Royston et al. [23] employed simulation and modeling in the investigation of the effect of time intervals between success cervical cancer screening. Wolstenholmme [28] used simulation and modeling to study the causes of waiting lists escalation. These studies demonstrate that System Dynamics models can be used to imitate reality, describe the characteristics of a given system and can be employed when the problem under investigation is too complex to be understood.

2 Methodology

Although several System Dynamics methodologies have been suggested by various researchers[4, 22], this study employed the Dynamic Synthesis Methodology (DSM) by Williams [27] which triangulates System Dynamics and case studies. DSM has the ability to explore and give insights into complex systems, while being able to use historical data from earlier research which enhances the treatment of causal loops. DSM is not only interactive but also synergistically employs SD ability to capture both the quantitative and qualitative aspects of the problem into a formal model. This makes SD suitable for enhancing our understanding of the complexity of non-linear systems stemming from their recurring nature, strong delays and feedback loops like those in maternal health care. 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. DSM has been a university based research effort, but has been tested and applied to case study problems in healthcare[24].

2.1 Suitability of system dynamics modeling in maternal health care

Maternal health care is a complex and dynamic system which exhibits variations among the interacting entities. Examples of maternal health variables that make it dynamically complex include; the unpredictable occurrence of complications during pregnancy and childbirth, changes in the availability and demand for Emergency Obstetric Care Facilities (EOCF) by mothers, dynamic changes in health care services and costs, availability of human resources for health (recruitment, retention and attrition), quality of healthcare services, geographical distribution of health care resources and delay of mothers to seek health care in case of complications. The suitability of SD methodology in solving maternal healthcare problems lies in its ability to shade more light on the key effects such as feedbacks, delays and non desirable outcomes. The use of simulation models employed by SD in trying to understand system complexities is very beneficial to health care managers and decision makers in the following ways:

(1) SD facilitates the recognition of missing data which could be vital for averting certain undesirable occurrences. For example in the case of Uganda, system dynamics can be important in identifying why despite the removal of user fees in government hospitals, the attendance of mothers to antenatal and prenatal care has remained very low.

(2) SD has the ability to encapsulate both the hard and soft aspects of research variables involved in maternal health care through the construction of causal loop diagrams to capture systemic delays, feedbacks and behavioral changes over time.

(3) SD has the potential of investigating policy resistance by interpreting the underlying reasons as to why certain interventions are not bringing about the desired outcomes. For example SD can be used to illuminate the

factors that have continued to vex the safe motherhood program in Uganda, despite the increased investment in reproductive health services.

2.2 The research design

Fig. 2 presents the research design framework used to conduct this research. This framework consists of six stages and was developed based on the Dynamic Synthesis Methodology by Williams [27]. This paper focused on the qualitative aspect of System Dynamics which involved the development of the descriptive framework and not quantitative model.

In the first stage, information related to maternal healthcare issues and associated problems was initially collected from related literature and documents. Mothers, health workers and administrators were interviewed to establish the current problems faced by delivery and uptake of maternal healthcare service. The study was used to determine the full range of activities and challenges associated with maternal healthcare. The factors affecting maternal healthcare as well as healthcare policies used for maternal healthcare were critically analysed and used to develop the descriptive framework which was presented to stakeholders for comments and improvements.

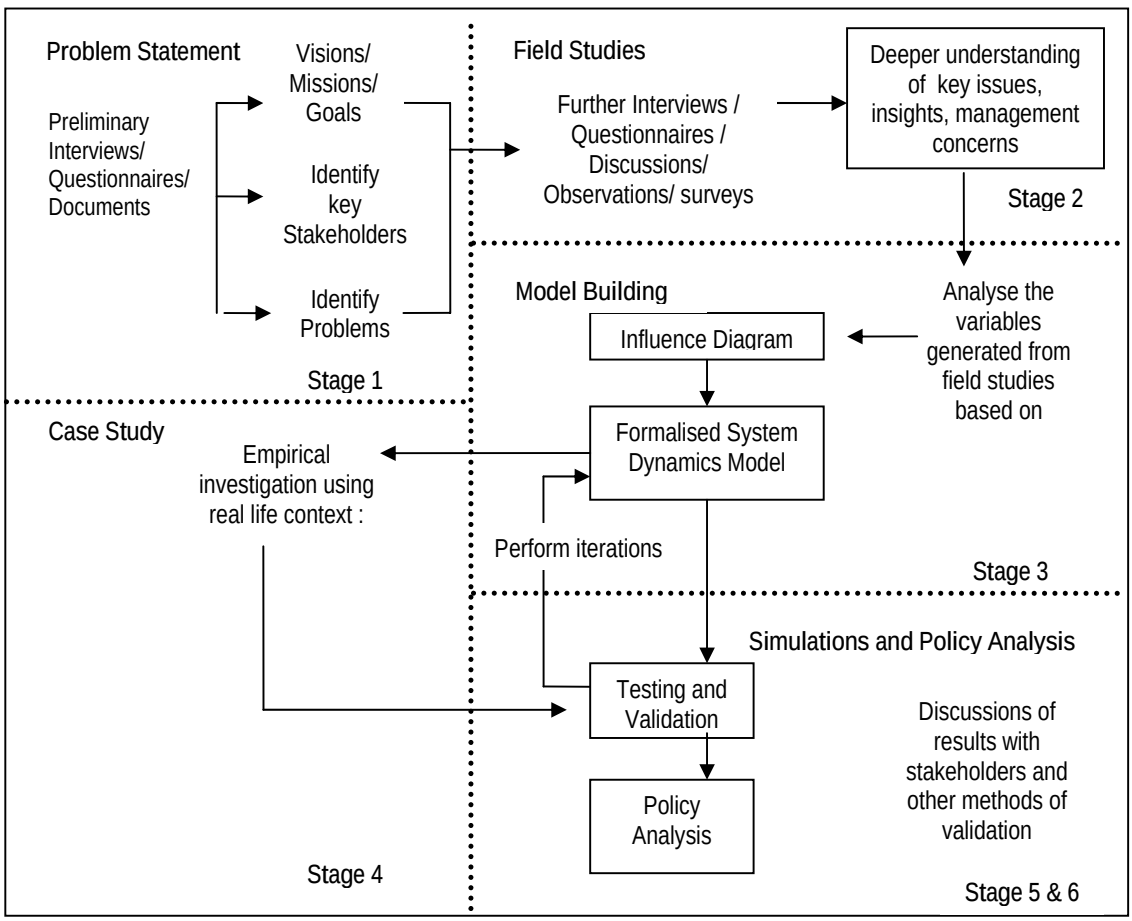

Fig. 2. Research design framework [source: Rwashana and Williams (2007) [24]]

The study was carried out in Mulago Hospital, the biggest referral hospital in Uganda. Mothers, administrators and nurses from the labour and maternity wards of Mulago hospital were interviewed using questionnaires to ascertain the key variables, their causes and effects. This was then followed by consultative discussions for the development of the system boundaries. The study was used to develop a descriptive framework highlighting the dynamics involved in the maternal healthcare system. Both quantitative and qualitative methods were used for data collection in this study. Qualitative data was helpful in trying to understand the

problem in detail and gain insights into expected improvements to achieve system effectiveness. According to Williams [27], the strengths of field studies are those of data collection and description of the phenomenon in its natural settings.

The primary data source was patient historical data, while journals and published research constituted secondary data sources. Self administered questionnaires and face to face interviews with mothers, doctors and nurses were conducted. Upon gathering the data, it was analysed using SPSS in order to describe the problem in its natural setting. This formed the basis for the development of a descriptive model in form of causal loop diagrams and reference modes.

Mothers. 229 mothers attending antenatal visits in Mulago were selected in the study. The sampling method was purely random in nature to reduce biasness and data was collected from mothers who had given birth at the maternity ward in one week. A questionnaire was used to establish selected bio-data such as level of education, age and number of pregnancies. Other information investigated was their knowledge about maternal healthcare, opinions of the quality of maternal healthcare service provided and the level of their trust in the healthcare system.

Nurses. Purposive sampling was used to select 20 nurses on duty to be interviewed with the aim of establishing their work conditions (workload and work pressure), skill level, remuneration and availability of training.

Administrators. Purposive sampling was used to select and interview 3 administrators who are in charge of the wards. The administrators gave information concerning the working conditions and skill level of the health workers, workload, salaries and quality of healthcare services provided in the hospital.

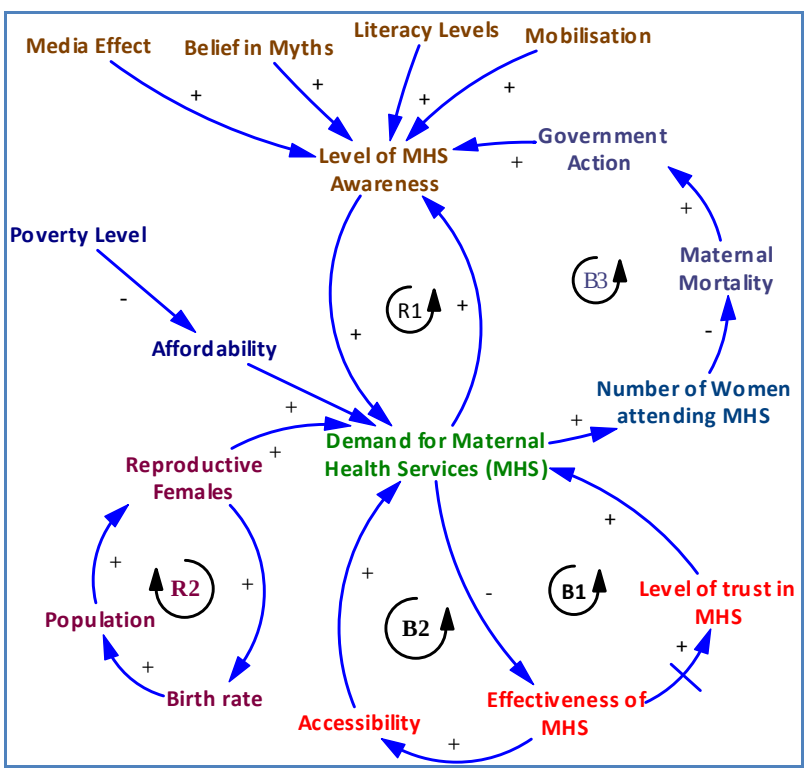

Fig. 3. Causal loop diagram for demand for Maternal Healthcare Service sub-system

Some of the key challenges that were highlighted in the study affecting the demand for MHS include: the unavailability of nurses when they are needed by the mothers, insufficient facilities such as beds, long distances to hospitals, cost of healthcare, trust in the healthcare system and insufficient knowledge concerning MHS. Some of the challenges faced by the nurses affecting the effectiveness of healthcare services include: large patient numbers, staff shortage, inadequate obstetric facilities, working overtime, work pressure resulting

into insufficient patient care time. The key variables found to be associated with maternal health and how they relate are explained in Section 3 below.

3 Descriptive framework for maternal healthcare

The descriptive framework showing the variables under play in maternal health care system (MHS) and their relationships has been presented in two causal loop diagrams (Fig. 3 and Fig. 4) for ease of understanding. One causal loop diagram focuses on the dynamics associated with the demand for maternal healthcare while the other focuses on the maternal healthcare service provision.

3.1 Demand for maternal healthcare subsystem

The dynamics illustrating the intricate and complex relationships among the factors associated with the demand for maternal healthcare are presented in Fig. 3. Fig. 3 shows two reinforcing loops (R_1 & R_2) and three balancing loops (B_1, B_2 & B_3) emerging from the relationships among the variables. Loop R_1, a reinforcing loop shows that an increase in demand for maternal healthcare services results into an increase in level of awareness which in turn increases the demand for maternal healthcare services. Loop R_2 presents the population dynamics affecting the demand for MHS. As the population increases, the reproductive females increase which in turn increases the population thus increasing the demand for MHS.

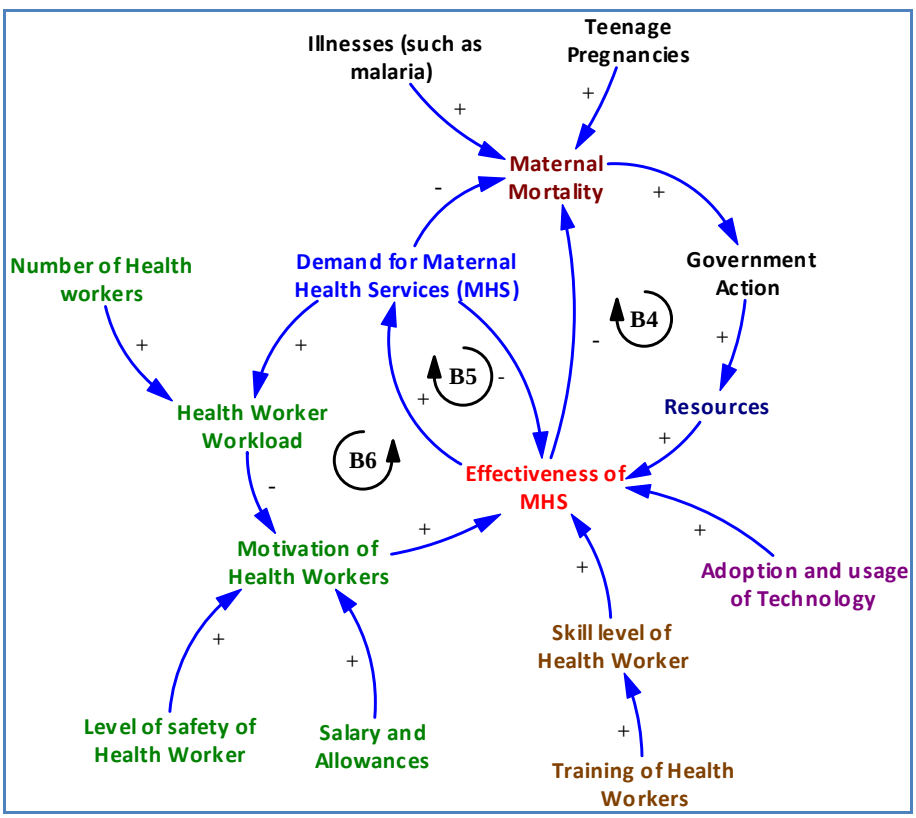

Fig. 4. Causal loop diagram for the Maternal Healthcare subsystem

Loop B_1, a balancing loop demonstrates that with increased effectiveness of the MHS, the level of trust in the MHS increases which increases the demand since more expectant mothers will seek to use the services. An increase in demand, however, results in a depletion of the healthcare resources and an increase in the workload of the health workers thus lowering the effectiveness of the MHS. Loop B_2 shows that with increased access to MHS, resulting from the effective MHS, more mothers will be able to attend MHS though if the increase

in demand is not matched with an increase in resources, this will lower the effectiveness of the MHS. Loop B_3 shows the dynamics involved in increased awareness. An increase in the level of awareness of the MHS offered resulting from mobilization and media results in increased demand which in turn lowers the mortality rate. An increase in mortality rate results in government action to increase awareness.

3.2 Maternal healthcare subsystem

The dynamics involved in MHS, presented in Fig. 4 demonstrate three balancing (B_4, B_5 & B_6). Loop B_4 demonstrates the need for government action (funding) towards increasing the effectiveness of MHS with the aim of lowering the mortality rate. Loop B_5 demonstrates that with increased effectiveness of the MHS, the demand for MHS increases since more expectant mothers will seek to use the services which in turn lowers the effectiveness of the MHS resulting from depletion of resources and lack of infrastructure upgrade. Loop B_6 shows the effect of increased demand for maternal health care on the workload of health worker and consequently on the mortality rate. When the demand for maternal health care services increases, there will be a corresponding increase in the demand for health worker. This impacts negatively on the health worker level, indicating a shortage in the availability of health worker. When the shortage in health worker level persists, the workload per health worker will also increase resulting in work pressure on the part of health workers. This impacts negatively on the ability of health workers to rescue mothers who are at risk of dying from pregnancy related causes and consequently maternal mortality increases.

4 Insights from the descriptive framework

The framework provides an integrated view of the maternal health system which can be used to promote communication and guide stakeholders in policy formulation. The different policies and interventions that need to be developed for the improvement of maternal healthcare can then be generated from a clear understanding of the complexity of the system.

4.1 Key issues for maternal healthcare services

The framework shows the following as key issues as far as maternal healthcare is concerned:
(1) With the growing population, there is need for government to increase funding towards the improvement of maternity healthcare services to meet the growing healthcare needs. Construction of new and maintenance of existing health centres for improved access of MHS for mothers. Recruitment of skilled health workers, providing refresher courses for existing staff as well as improving staff remuneration would greatly improve the effectiveness of MHS. There is need to avail sufficient emergency obstetric care facilities (drugs, equipment and supplies) to cater for the growing population as well as increase mobilization for improved awareness.
(2) There is need to upgrade the infrastructure upgrade and adopt new technologies to meet the demand of the growing population, provide faster and improved healthcare services.
(3) Affordability of the healthcare services increases the demand of maternal healthcare. For healthcare services to be affordable, the government has to highly subsidize the cost of MHS as well as continue the efforts towards reduction of poverty levels to enable the mothers afford the health services.
(4) To increase the demand for healthcare services, there is need to build the level of trust in the health system by providing quality MHS.
(5) An increase in awareness of the availability of MHS will increase the demand for MHS. Awareness is associated with the belief in myths, level of literacy of women, effect of media and effectiveness of mobilization. The short term goals would be to educate mothers concerning availability of MHS, dangers of diseases during pregnancy, the dangers of lack of family planning (un-spaced births). One of the long term goals would be to ensure that the level of literacy of women increases.
(6) There is need for government to set policies towards the population growth since it is becoming very difficult to meet the growing MHS needs of the current population.

(7) Maternal mortality can be reduced by improving the MHS delivery as well as educating the girl child concerning teenage pregnancies and the management of illnesses that cause maternal mortality such as malaria and sexually transmitted diseases (STDs).

4.2 Health information systems

The framework (Fig. 3 and 4) present various variables which demonstrate the important data that needs to be collected for improved decision making in the maternal healthcare. The framework demonstrates the need for an integrated maternal healthcare information system that is relevant to the Ugandan situation thereby capturing the following:
(1) Personal data of the women which includes the details of the women; bio data, education level, profession, area of residence and health profile.
(2) Health worker information which includes data, profession, skill level, training undertaken, salary, allowances and workload.
(3) Resources used for maternal health services such as obstetric equipment, supplies, bed capacity, number of theatres, wards,
(4) Management of stocks (drugs, facility) which includes stocks received, purchased and stocks going out.

5 Conclusion and future work

This paper has made an attempt in examining the power of System Dynamics in improving our ability to understand why maternal healthcare problems pervades various policy interventions that are employed to lower maternal mortality. The study findings reveal that availability and continuous improvement of healthcare infrastructure, improved access to healthcare facilities, skilled attendance at birth and continuous improvement in EMOC facilities are the crux of maternal healthcare service provision. The framework developed in this study recognizes the fact that a number of feed back structures can have great policy implications for maternal health care. Basing on the findings, managers for maternal and reproductive health services need to investigate the possibility of developing tools based on System Dynamics that can give better understanding of how best maternal health factors can be combined in order to reduce maternal mortality. Future work involves the development of a quantitative simulation model that will be used to test different healthcare policies using "what if" analysis with the aim of improving maternal healthcare towards the lowering the maternal mortality rates.

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