Chapter 3

PREVALENCE, PREVENTION, AND CONTROL OF DIABETES

This chapter deals with the development of a system dynamics model for prevalence, prevention, and control of diabetes in India. The diabetes is growing like an epidemic in India and healthcare system is not ready to handle this sudden surge. The healthcare system in the Indian context is traditionally developed to tackle acute disease and disease related to mother and newborn child. There is need of a fresh planning for long-term care for a disease like diabetes in India. The government and healthcare providers still use conventional methods of evaluating and managing each aspect of the disease separately. These tools are not capable of addressing the dynamic complexity of diabetes. This research proposes a system dynamics model for diabetes and tests outcomes of policy measure taken to control the growth of diabetes. The research uses a case of Indian city Varanasi for discussing the system dynamics model for diabetes. The model can be easily adapted for other cities with changing the input variables.

3.1 State of Diabetes in Varanasi

Varanasi is an ancient city in northern part of India. The region is considered underdeveloped and has been deprived of significant economic and infrastructural development since many decades. Though healthcare facility in the city has improved in recent years, it is hardly sufficient to fulfill the demand for healthcare in the city. Moreover, thousands of patients from the catchment area visit the city daily and it puts additional stress on already inadequate healthcare infrastructure.

Recently, the city has witnessed rapid westernization of lifestyle and food consumption. The food intakes of the residents of the city include high carbohydrate, high fat, and sugar, which exposes them to the risk of the metabolic disorder. The diabetes management in the city is marred by gender bias against females, poor quality of health services, myths, and lack of disease awareness compounded with a small number of prevention and awareness programs. There is hardly any research to estimate the prevalence of diabetes in Varanasi and surrounding areas. There is urgent need to estimate the prevalence of diabetes in recent future and plan infrastructure and resources accordingly. This research tries to fill this gap and attempts to estimate the prevalence of diabetes in Varanasi by the year 2030. The thirteen-year duration is big enough to see the changes due to policy measures. The duration more than twenty years will make the group making wild guesses about the future and won't be appropriate for the planning purpose.

3.2 Methodology

This section describes the steps of model development for the diabetes prevention and control. The system was defined such that it is neither too simple to address the complexity nor too complex to handle. The method used in this research is computer simulation method known as System Dynamics. The simulation is a method that allows experiment on the system through a computer-based model of the system (Yih, 2010). Computer simulation is broadly used in healthcare in an area of healthcare delivery, cost minimization and healthcare safety and quality (Issenberg, 2006; GABA, 2007; Cohen et al., 2010). The various simulation modeling approaches include Monte Carlo Simulation (Geis et al., 2011; Critchfield, 1986), Discrete-Event Simulation, Object Oriented Simulation, System

Dynamics and Agent-Based Modeling(Halpern et al,2000; Günal et al.,2010; Banks,1998; Forrester,1971; Brailsford et al., 2009;Sternman,2000;Forrester,1994; Homer et al.,2004).

The literature suggests that system dynamics model has unique ability to mimic the real world scenario. It can address the complexity, nonlinearity, and feedback loop structure attached to the healthcare system (Maryani et al., 2015).This research uses system dynamics (SD) model because it is simple, powerful, useful and natural for addressing the dynamic complexity of health care system.

The SD approach is based on control theory, and it postulates that system behavior is caused by system structure. The hypothesis is driven by the insight the modeler has about the system behavior. Without intelligent guess about the operation of the system, an SD model is futile or at least extremely laborious. The various types of variables used in SD model are:

1. *Stocks:* A stock is a term for any entity that accumulates or depletes over time.
2. *Flows:* A flow is the rate of change of the stock.
3. *Auxiliary Variables:* Variable which changes the flow or combines with another auxiliary variable to produce auxiliary variable.
4. *Table Function:* If the relationship between two variables is not linear, table functions are used to represent the relationship.

The researchers have used System Dynamics model for developing tools for chronic disease prevention and control. The research adopts diabetes and pre-diabetes stock and flow model developed by Homer et al. (2004) as the base model for the development of a model for predicting the state of diabetes in Varanasi by the year 2030.

3.2.1 Focus Group Meetings and Participants

A focus group of eight people having the following qualification was constituted for the study. The size of eight participants is appropriate for the study as a group with higher than eight members, is hard to handle (Fern, 1982).

Table 3. 1: Details of Focus Group for the Model Development

Participant	**Job Profile**	**Qualification**
1	Researcher	B.Tech, MBA, Diabetes Educator
2	Endocrinologist	MBBS,MD, Fellowship in Diabetes
3	Cardiologist	MBBS,MD
4	Physician	MBBS
5	Psychologist	PhD
6	Social Worker	BSc, Diabetes Educator
7	Nutritionist	MSc (Nutrition)
8	Dentist	BDS

Between January 2015 and January 2017 the focus group worked on the development of a system dynamics model focused contributing towards the growth of prevalence of diabetes. Four formal meetings, each taking one day, were conducted to discuss the various aspects of the defined system.

Meeting 1: Model Conceptualization

The focus group met with defined objectives of the meeting. The participants very briefed about the stock-and-flow structure.The agenda for the meeting included (1) reviewing the principle of SD methodology(2) brainstorming about drivers of diabetes like obesity, stress, and lifestyle (3) mapping the relationship among the various drivers.

Meeting 2: Outline Development

The second day of the meeting involved: (1) discussing the simplified cause and effect diagram (2) understanding the behavior of the system over time (3) Identifying the source of empirical data (4) Finalizing the stock, flow and auxiliary variable for the system dynamics model.

Meeting 3: Development of Model

Using the variables finalized in the earlier meeting a system dynamics model was developed. The parameters were estimated using the empirical data from various sources. The model was simulated for different policy scenarios and the results were analyzed.

Meeting 4: Finalization of Model

The model was fine-tuned and the results were explained to the focus group for discussion and validation.

3.2.2 Model Structure

As suggested in literature the focus group strived to achieve a diabetes system models having following characteristics (Jones et al., 2006):

1. Generic enough to be adaptable for another chronic disease.
2. Realistic enough to reproduce the historical data derived from other epidemiological studies.
3. Comprehensible enough to test various policy scenarios.
4. Broad enough to include various policy measures considered during the third meeting.
5. Doesn't require guesswork beyond what focus group agrees upon.

The study adopts a model (Homer et al., 2004) as described in Figure 3.1 as preliminary stock and flow model. After various iterations of the focus group, we were able to finalize the customized stock and flow model for the population being studied. (Undx: undiagnosed; Dx: diagnosed; PreD: prediabetes; D: diabetes)

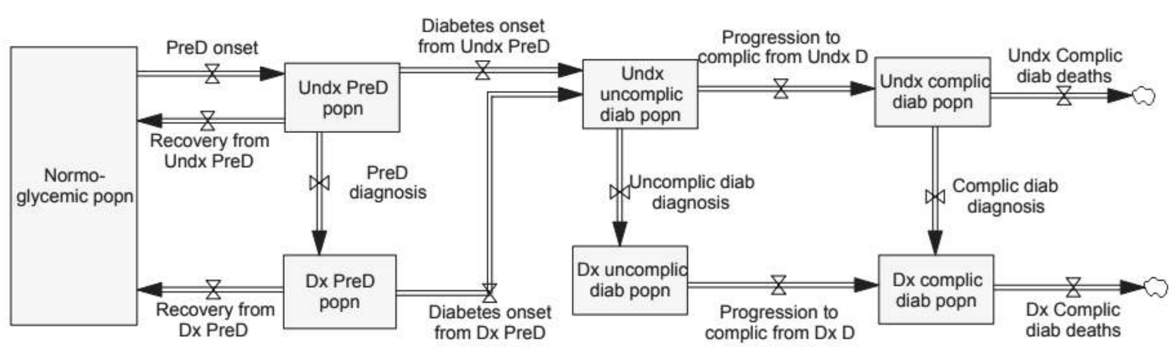

Figure 3. 1: Preliminary Diabetes and Prediabetes Population SFD

3.2.3 Parameters Finalization and Initialization

Using the secondary research and input of the Focus Group the following parameter values and initialization values were estimated.

Table 3. 2: Parameter Finalization and Initialization

Parameter Name	Parameter Description	Type of variable	Initial Value
Work Schedule	Effect of work schedule on physical activity (Multiplier)	Auxiliary Variable	0.5
Physical Disabilities	Effect of physical disabilities on physical activity (Multiplier)	Auxiliary Variable	0.8
Environment	Effect of the environment on physical activity (Multiplier)	Auxiliary Variable	0.5
Calorie Intake	Intake of the calorie (Maximum being 100 Unites)	Auxiliary Variable	100
Resting Metabolism	Consumption of calories without active physical activities	Auxiliary Variable	50
Birth Rate	Birth Rate (Taken as birth rate of India)	Auxiliary Variable	0.0193
Death Rate	Death Rate (Taken as death rate of India)	Auxiliary Variable	0.0073
Normo-Glycemic Population	Normal Non Diabetic Population	Stock Variable	800000
Undx PreD Popn	Undiagnosed Prediabetes Population	Stock Variable	150000
Dx PreD Popn	Diagnosed Prediabetes Population	Stock Variable	150000
Undx Uncomplic diab popn	Undiagnosed Uncomplicated Diabetes Population	Stock Variable	50000
Dx Uncomplic diab popn	Diagnosed Uncomplicated Diabetes Population	Stock Variable	50000
Undx Complic diab popn	Undiagnosed Complicated Diabetes Population	Stock Variable	25000
Dx Complic diab popn	Diagnosed Complicated Diabetes Population	Stock Variable	25000

3.2.4 Causal Loop for the System Dynamics Model

Causal Loop Diagrams (CLD) are an important tool for representing the feedback structure of the system. A CLD consist of variables connected by arrows denoting the causal influences among the variable, which helps in identifying the important feedback loops in the diagram.

The variables are related by causal link, shown by arrows. A positive link means that if the cause increases, the effect increases above what it would otherwise have been, and if the cause decreases, the effect decreases below what it would otherwise have been. Similarly, a negative link means that if the cause increases, the effect decrease below what it would otherwise have been, and if the cause decreases, the effect increases above what it would otherwise have been. The definition of link polarity and its mathematical explanation is listed in Table 3.3.

Table 3. 3: Explanation for Link Polarity

Symbol	**Interpretation**	**Mathematics**
$x \overset{+}{\rightarrow} y$	All else equal, if x increases (decreases), the y increases (decreases) above (below) what it would have been. In the case of accumulations adds to y.	$\frac{\partial y}{\partial x} > 0$ In case of accumulations, $y = \int_{t_0}^{t} (x+..)dx + y_{t_0}$
$x \overset{-}{\rightarrow} y$	All else equal, if x increases (decreases), the y decreases (increases) below (above) what it would have been. In the case of accumulations subtracts from y.	$\frac{\partial y}{\partial x} < 0$ In case of accumulations, $y = \int_{t_0}^{t} (-x+..)dx + y_{t_0}$

The figure 3.2 below depicts the causal loop diagram for the system dynamics model. The CLD was analyzed and reinforcing and balancing loops were identified.

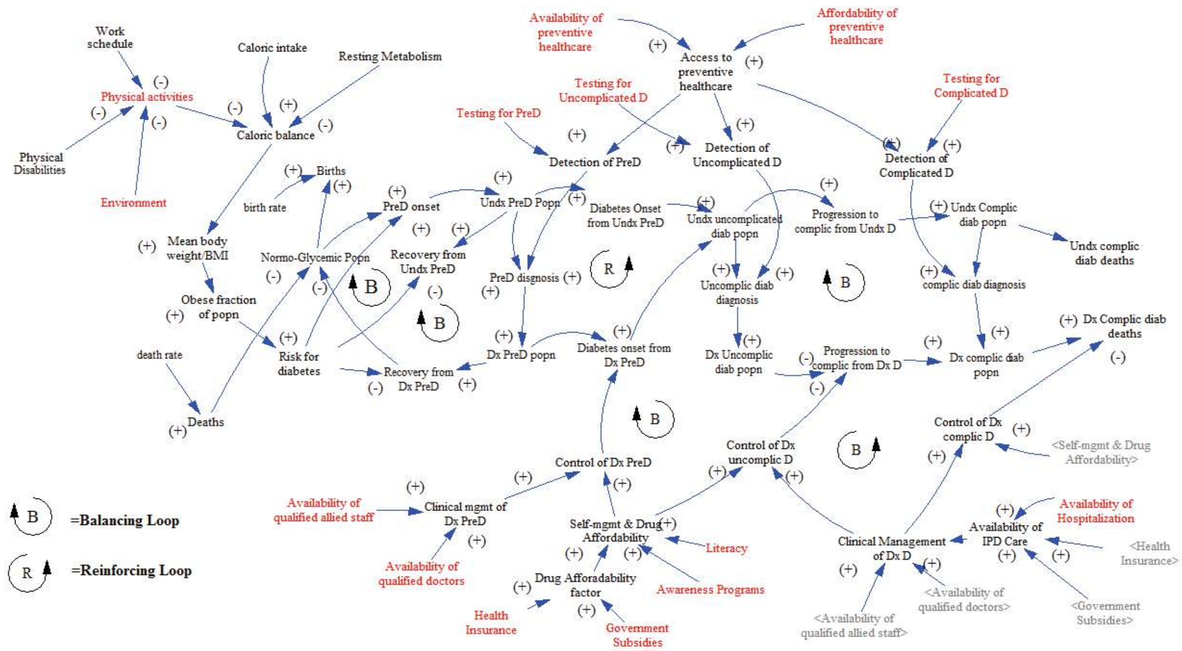

Figure 3. 2: Causal Loop Diagram for the System Dynamics Model

3.2.5 Final Stock and Flow Model

The system can be divided into two parts namely upstream (prevention related variables) and downstream (treatment-related variables).Using the secondary research and input of the Focus Group the parameter values and initialization values were estimated. The proposed system dynamics model uses availability & affordability of preventive care, testing of diabetes and prediabetes, availability of qualified doctors and support staffs, availability of hospitals, health insurance and government subsidies as the policy variables. Stock-flow diagrams (SFD) are only graphical representations of the system; alone they are not able to give any useful insight about the system. To be able to reason and analyze the behavior of the system we need to quantify its variables and also the relation between its variables also need to be defined mathematically. SFD allows us to represent the relations among variables in terms of differential or integral equations.

$$Stock_{final} = Stock_{initinal} + \int_0^T (inflow - outflow)dt$$

The model uses following steps in the process:

Initialization Phase

1. Create a list of all equations in required order of evaluation.
2. Calculate initial values for all stocks, flows, and auxiliaries (in order of evaluation).

Iteration Phase

1. Estimate the change in stocks over the interval DT (Step size).
2. Calculate new values for stocks based on this estimate.
3. Use new values of stocks to calculate new values for flows and auxiliaries.
4. Add DT to the simulation time.
5. Stop iterating when Time >= Stop Time

This research has used the year 2017 as year Zero, while the step size used is one year. The numerical integration method used for the model is Euler Method. The reason for selecting the method is its simplicity and availability as an inbuilt option in the Vensim tool. The Euler Method uses following steps in processes of calculating the value of stock:

$$\Delta Stock = DT * Flow\ at\ begining\ of\ DT$$

$$Stock_t = Stock_{(t-DT)} + \Delta Stock$$

$$Stock_t = Stock_{(t-DT)} + DT * Flow_{(t-DT)}$$

The Figure 3.3 below depicts full Stock and Flow Diagram (SFD) for the system dynamics model developed for diabetes management in Varanasi.

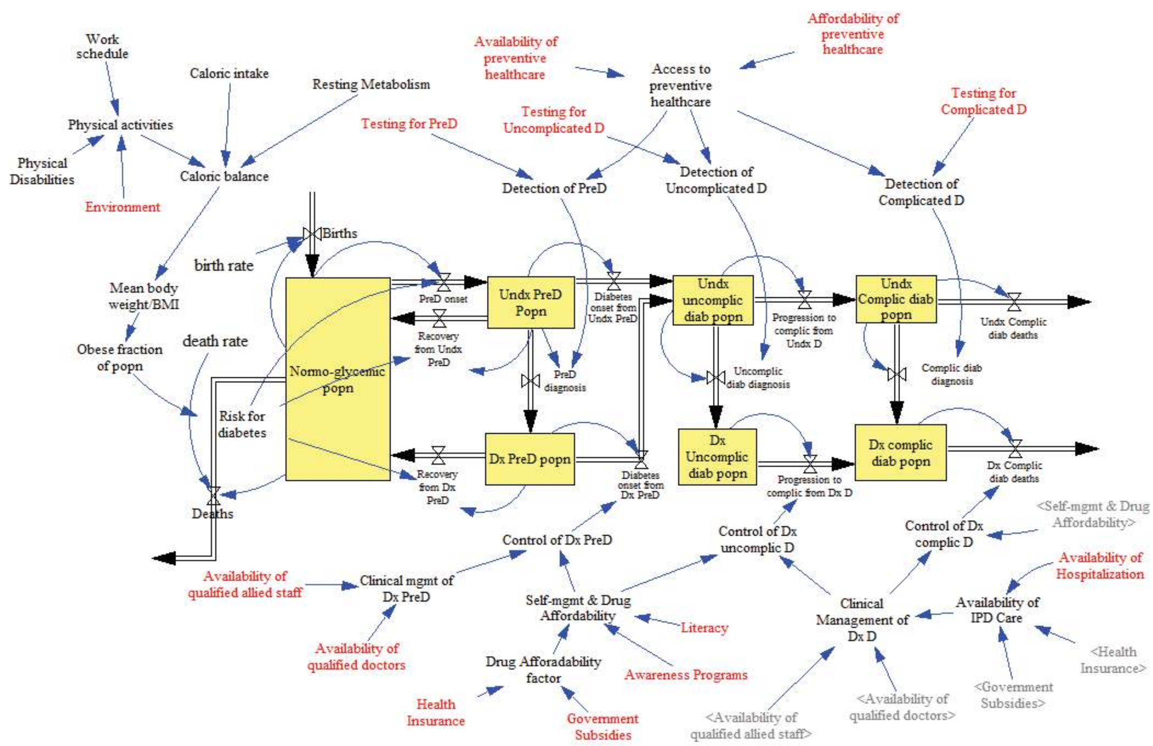

Figure 3. 3: Overview of the Full Stock and Flow Model for Diabetes

3.2.6 Base Line Model Behavior

The baseline behavior of the system was analyzed using the initial value of the critical variables as listed in Table 3.4.The output of the baseline behavior is listed in Figure 3.4 and 3.5.It was assumed that the critical variables identified in the system are affected by the policy measures implemented over a period of next ten years.

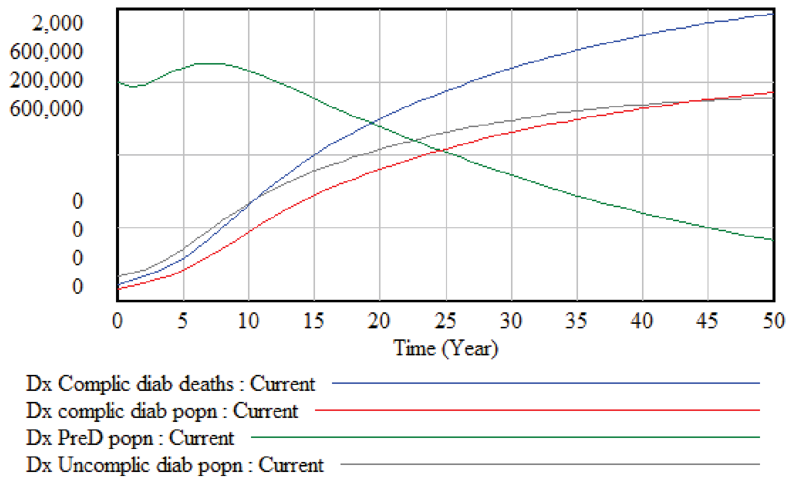

Figure 3. 4: Key Variables without Policy Interventions (A)

As visible from figure 3.4, in the baseline scenario the variables like diagnosed diabetes complication, diagnosed diabetes death, and diagnosed uncomplicated diabetes population will continuously increase and saturate after fifty years, while the diagnosed Prediabetes population will initially increase then start decreasing.

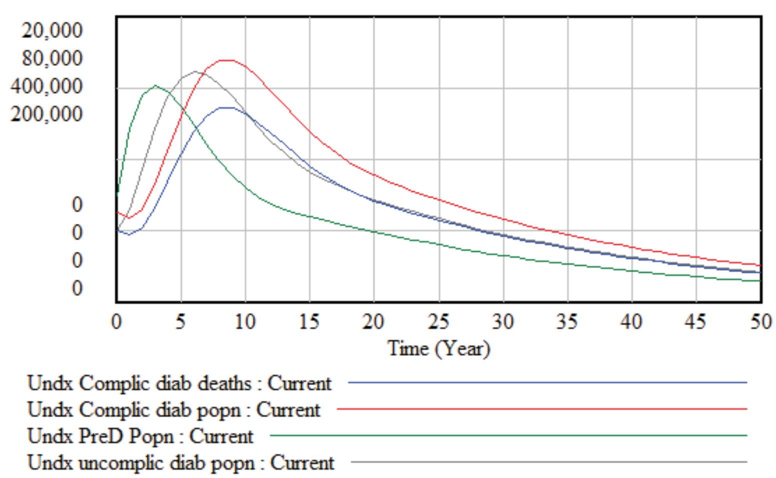

Figure 3. 5: Key Variables without Policy Interventions (B)

In the baseline scenario, the variables like undiagnosed diabetes complication, undiagnosed diabetes death, undiagnosed Prediabetes and undiagnosed uncomplicated diabetes population will initially increase and then start decreasing and saturate after fifty years, Figure 3.5. The possible reason behind this behavior is establishment of early diagnosis and early prevention of diabetes in the community.

The study identifies variables like environment, testing of Prediabetes, testing of uncomplicated diabetes, testing of complicated diabetes, availability of preventive health care; affordability of the preventive health care, availability of qualified doctors and staffs, health insurance, government subsidies, awareness program, literacy and availability of hospitalization as the critical indicators. The baseline values are estimated as performance on an indicator on a percentage scale. This value was taken from secondary research and focus group discussion. The targeted value is the resultant value targeted after the successful policy implementation. The targeted values after policy intervention were suggested by the focus group during the meetings. The state of these variables in developing countries was taken in to account at the time of deciding the variables (Tables 3.4). It was assumed that the targeted value of the policy variable will be achieved in ten years with the linear growth.

Table 3. 4: Baseline and Targeted Values for the Policy

S/N	Critical Variable Identified	Baseline Value	Targeted Value
1	Environmental condition	50%	80%
2	Testing of prediabetes	20%	60%
3	Availability of preventive care	50%	80%

4	Testing of uncomplicated diabetes	50%	80%
5	Testing of complicated diabetes	100%	100%
6	Affordability of Preventive care	50%	80%
7	Availability of qualified doctors	20%	80%
8	Availability of qualified staffs	20%	80%
9	Health insurance inclusion	20%	100%
10	Government subsidies	25%	50%
11	Diabetes awareness program	25%	100%
12	Health literacy	40%	80%
13	Availability of hospitalization	50%	80%

3.3 Results and Discussions

This section discusses the results of the simulation run with and without policy interventions. The Table 3.5 below lists the result of a simulation run for the baseline model.

Table 3. 5: Results of the Simulation Run

Year	Undx Uncomplic diab popn	Dx Uncomplic diab popn	Undx Complic diab popn	Dx Complic diab popn	Total
2017	50000	50000	25000	25000	150000
2022	85014	166727	20594.4	109643	384000.4
2027	63585.4	219735	16302	204169	505818.4
2030	**52985.7**	**215808**	**13565.6**	**235190**	**519579.3**
2032	46904.2	206247	12015	244921	512119.2
2037	34335.3	172042	8816.56	240683	457913.9
2042	24953.1	135325	6415.86	212248	380984
2047	18073.6	102965	4649.84	175220	302955.4
2050	14881.1	86515.6	3829.26	152854	260130

As the results of the simulation shows, the prevalence of complicated and uncomplicated diabetes by the year 2030 will be 0.52 million in Varanasi. At present growth rate (1.19%) the population of Varanasi will be 1.46 million by years 2030. This data gives us the prevalence of diabetes by the year 2030 at 35.64 % (calculated by dividing the sum of uncomplicated and complicated diabetes population with total population), which is very alarming. To achieve the doctor-patient ratio of 1:1000 and bed patient ratio of 1:1000 we will need 520 doctors as well as beds in Varanasi for the diabetic population alone. Moreover, this infrastructure needs to be specialized in diabetes care to provide health care effectively.

As depicted in Figure 3.6, the prevalence of diabetes in Varanasi will increase and peak by the year 2030 and will decrease thereafter. The possible reason for this peaking and decline is due to the negative feedback mechanism of the system. This growth of diabetes resembles the growth of epidemic hence the disease is aptly named next epidemic.

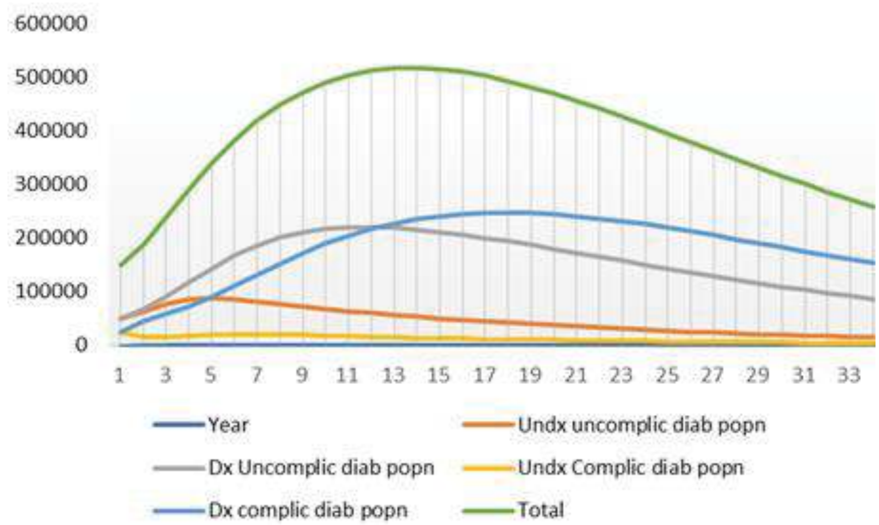

Figure 3. 6: Prevalence of Diabetes in Varanasi

3.3.1 Results of Policy Interventions

India has one of the poorest healthcare infrastructures in the world and spends below 5% of GDP on healthcare (Kamath and Kamath, 2017). Implementing the policy measures to achieve the target results (Table 3.4) will require upscaling the spending by many folds. The focus group agreed that the planning and implementation duration for such a humongous policy measure should be taken as ten years, at least. The ramp function is taken as an approximation for the effect of policy measures implemented.

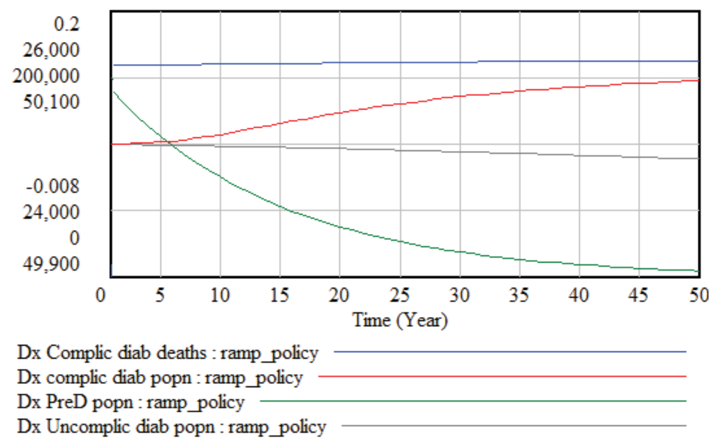

Figure 3. 7: Key Variables with Policy Interventions (A)

The results indicate that the diagnosed complicated diabetes death and diagnosed uncomplicated diabetes population will be stable and decrease with very slow rate (Figure 3.7). Diagnosed prediabetes population will decrease exponentially while diagnosed complicated population will increase after implementation of the policy measures.

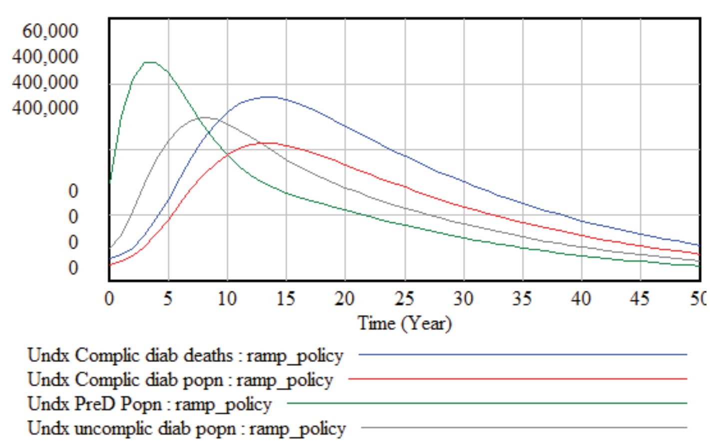

Figure 3. 8: Key Variables with Policy Interventions (B)

The results of the simulation indicate that undiagnosed diabetes death, undiagnosed complicated diabetes population, undiagnosed prediabetes population and undiagnosed uncomplicated diabetes population will initially increase and then decrease as observed in baseline behavior (Figure 3.8), but the peak of the incidence will be delayed and maxima will be slightly reduced due to effect of the policy measures. The following table lists the result of the simulation run after policy implementation (Table 3.6)

Table 3. 6: Result of Simulation Run after Policy

Time (Year)	**2017**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**	**2050**
Undx Uncomplic diab popn	50000	213288.7	239920.9	**184719.2**	141517.1	111114.3	86620.08	74268.72
Dx Uncomplic diab popn	50000	49999.12	49998.41	**49997.63**	49996.65	49995.54	49994.33	49993.56
Undx Complic diab popn	25000	93152.98	192570.4	**206604.7**	176603.8	142562	113066.8	97765.14
Dx Complic diab popn	25000	25016.03	25072.82	**25156.34**	25236.46	25303.14	25356.72	25383.39
Total	150000	381456.9	507562.5	**466477.9**	393353.9	328975.1	275038	247410.8

Comparing the results before policy intervention (Figure 3.6) with the results after policy intervention (Figure 3.9) we conclude that diagnosed diabetes population will decrease after policy intervention while undiagnosed diabetes population will increase and then decrease in long run.

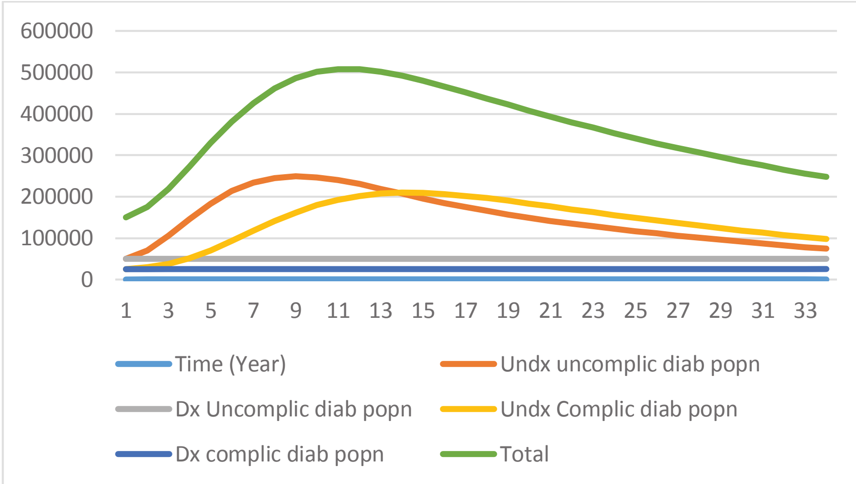

Figure 3. 9: Prevalence of Diabetes after Policy Intervention

3.4 Conclusion

The model described in this thesis can help policymakers design strategies for addressing the burden of diabetes at national and regional level. Though the simulation is done for the city under the study, the model can be easily tuned to get a picture at the national level. The simulation model gives the prevalence of diabetes in Varanasi for the years 2030 as 0.52 million and 35.64 %. The study suggests involving 520 specialized doctors for management of diabetes in the city. Assuming fifty beds per hospital, the city will need starting additional nine district level hospitals (presently two) to support this surge in demand for diabetes management. The same health infrastructure can be utilized for providing the prevention and treatment of other chronic diseases as well. The study also concludes that for all other variables being constant the number of patients having diabetes with complication will keep increasing. This scenario will result in an increased burden of diabetes. The timely detection and treatment of the disease can enhance the life expectancy but the lifetime cost of diabetes management will increase further. The research test the effect of policy measures by using ramped increased in the key variables over ten years. The results conclude that the total population suffering from diabetes will increase irrespective of the policy measures, hence policymaker need to tackle diabetes at prediabetes stage and make healthcare available at affordable cost.The method suggested by the study can be easily adapted for developing the similar models for other chronic diseases like Asthma, Chronic Obstructive Pulmonary Disease (COPD) and Tuberculosis.

3.5 Managerial Implications

The study suggests the healthcare infrastructure in Varanasi is not adequate. There is an urgent need of developing adequate healthcare infrastructure for chronic care in Varanasi. The planning of the disease management should be such that it affects the policy variables selected in the study positively. That means there should be planning to make preventive and curative care available at an affordable cost in the city.

As depicted in the SFD the prediabetes stage is the only stage, from where the progression of the disease could be reversed. The policymakers should focus on preventive measures like clinical management of prediabetes, training on self-management of diabetes and related complications, providing the antidiabetic drugs and insulin at an affordable cost. The awareness programs about diabetes should be made compulsory in school, colleges, and workplaces. Every school should have a playground and sports period should be made mandatory. In addition to this policymakers should also focus on bringing the pollution level down in the city. The study is first of its kind and depicts the state of diabetes prevalence in Varanasi in coming decades. The system dynamics model acts as a tool for testing various policy measures and analyze their effects.

As the results of the study suggest, the healthcare infrastructure is not adequate to address the surge of diabetes in Varanasi. The next chapter discusses the facility planning, logistic planning, and resource allocation strategies for diabetes care in the context of Varanasi.