

System dynamics modeling for tooth decay treatment in Brazilian children

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Abstract: Prevention and health promotion are considered important strategies to control oral diseases. Dental caries is preventable disease and remains the most common chronic disease that affects mainly low income children and still considered the main cause of tooth loss in adulthood in Brazil. The aim of this study is to present a System Dynamics model (SDM) specifically developed with the Stella Architect software to estimate the cost and clinical hours required to control the evolution of dental caries in preschool children in Maringá, Brazil. Two main strategies to control caries were considered in the model: the application of fluoride varnish on teeth presenting white spots, and the use of Atraumatic Restorative Treatment (ART) in cavitated carious lesions without pulp involvement. The parameters used in the model were: number of people covered by a local oral health team = 4,000; number of children up to 5 years = 7% of the population; children's decayed, missing, filled teeth (dmft) index = 2.4; time/cost of 4 applications of fluoride varnish = 5 minutes/US\$ 0.716; and time/cost of each ART restoration = 15 minutes/US\$ 1.475. The SDM generated an estimated total cost of US\$698.00, and a total of 112 clinical hours to treat the population in question. The use of the SDM presented here has the potential to assist decision making by measuring the material and human resources required to prevent and control dental caries at an early age.

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Introduction

Oral health education, especially during childhood, can be a powerful ally to prevent chronic diseases, such as dental caries, which are triggered by the high consumption of free sugars present in their diet.¹ The acquisition of healthy habits promoted by oral health education, in association with programs to control dental caries evolution, can prevent future tooth loss during adulthood.² In Brazil, for instance, while children up to 5 years present a mean decayed, missing, filled teeth (dmft) index of 2.43, people aged between 65 and 74 years show a mean DMFT of 27.53, with high prevalence of tooth loss.³ In the 2010 Global Burden of Disease study, among 291 evaluated diseases, untreated caries in permanent teeth was considered the most prevalent condition

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worldwide, and the untreated caries in deciduous teeth were the 10th most prevalent condition.⁴

Additionally, in Brazil caries can also vary according to the socioeconomic condition, affecting mainly the low income population.^{5,6} Inequalities in access to healthcare services represent one of the main challenges faced by health provision policymakers. To minimize the social differences and improve basic healthcare provision in Brazil, the Family Health Strategy (FHS) was created in 1994, initially denominated as Family Health Program (FHP).⁷ Basically, the FHS consists of teams of health professionals that visit the population within a particular geographical area, aiming at disease prevention, treatment, and rehabilitation.⁸ The oral health teams started implementation by Portaria GM 1,444⁹ with regulation by Portaria GM 267.¹⁰ In 2004, the Brazilian Oral Health Policy, also known as *Smiling Brazil*, was established to pursue universal oral care within the Brazilian Unified Health System.¹¹ Since then, emphasis has been placed on interventional educational approaches and preventive programs, which are considered the priority to deal with chronic diseases, such as dental caries. Nonetheless, early childhood caries (ECC) is still considered a significant public health problem, particularly among the most socially and economically disadvantaged minorities.^{12,6}

Educational activities involving patients are the main components of the preventive philosophy, empowering people with knowledge about health/disease processes for the development of autonomous oral health self-care within the family context.¹³ Because the costs of treating oral diseases are also associated to indirect costs, such as productivity losses due to absenteeism from work,¹⁴ actions to prevent and control caries early in life are important instruments to maintain oral health later in adulthood. Moreover, parents/guardians often report the heavy financial burden involved in seeking oral treatment late, especially when pain is present.¹⁵

System Dynamics modeling is well suited to deal with public health issues, giving support to public policy planning, by estimating future demands and resources.¹⁶ Thus, different scenarios emerging from epidemiological surveys can be more promptly

and appropriately dealt with. Because public health interventions tend to operate in dynamically complex systems, decision making processes require tools that can provide support to public policy planning, estimating future demands and resources. System dynamics is a methodology and mathematical modeling technique developed to frame, understand, and discuss complex issues and problems. Recently, system dynamics modeling has been used to better understand the effects of preventive programs in complex health systems and their impact on the health status of populations.¹⁷

Therefore, the objective of the present study is to present a System Dynamics model (SDM) specifically developed to estimate the cost and clinical hours required to control the development of dental caries lesions in preschool children in Brazil.

Methodology

In the present study, an SDM was developed to estimate the costs and the clinical hours required for the treatment of preschool children up to 5 years with white spots and cavitated carious lesions using either fluoride varnish or ART, depending on the stage of the disease.

System dynamics model

The SDM used in this study was developed using the Stella Architect software. The SDM was created using stock and flow diagrams. Stocks are cumulative resources of a system, while flows represent the rate of change of a stock¹⁸ (Figure 1). In the present

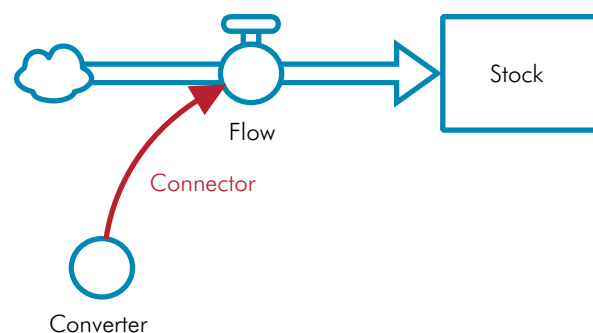


Figure 1. Basic components of one representative stock and flow diagram of System Dynamics model.

study, the stocks were represented by “teeth with carious lesions”, “teeth with white spots”, and “total material costs”.

SDM development started with the establishment of a systemic vision of the problem, participation in courses and events, discussions, and exchange of information and experiences with specialists in system dynamics modeling. Based on this systemic vision, data from oral educational and preventive actions conducted at an Early Childhood Education Center in the city of Maringá, Brazil were used to define the goals (unpublished data).

The first step for SDM development was a diagram of inventories and flows created by the team of researchers, containing the main ideas and data. Based on this initial diagram, sketches of the model were drawn. A specialist in engineering, mathematics, statistics, and system dynamics was consulted, and all the required adjustments were conducted so that the SDM would respond to the established goals. Emphasis was placed on developing an SDM that was simple, as well as easy to understand and apply to a range of local realities by health managers and professionals.

Cost and clinical hours estimation

The application of fluoride varnish and ART restorations were conducted by an oral health team (OHT), composed by a dentist, an oral health technician, and an oral health assistant.¹⁰ OHT salaries, as well as the equipment and instrumentation already in use were not considered in the model, as these are fixed costs that already existed regardless of the interventions proposed. Only the cost of the materials for the treatment of white spots and cavitated carious lesions using either fluoride varnish (S.S. White Artigos Dentários Ltda, Rio de Janeiro, Brazil) or the high-viscosity glass ionomer (Ketac Molar EasyMix, 3M ESPE, Sumaré, Brazil) used in the ART restorations were considered in the model. Prices currently practiced in the market were obtained from “Banco de Preços em Saúde” (<http://www.saude.gov.br/gestao-do-sus/economia-da-saude/banco-de-precos-em-saude>), and “Painel de Preços” (<http://paineldepresos.planejamento.gov.br/>) website.

To determine the time involved in the procedures, the proposed interventions were performed in children up to 5 years attending an Early Childhood Education Center in the city of Maringá. The procedures were conducted after parents/legal guardians signed an informed consent. An initial epidemiological survey was conducted by calibrated researchers, and the International Caries Detection and Assessment System (ICDAS) index was used to allocate the children according to their risk group, prioritizing care to those at higher risk.¹⁹ Children presenting teeth with white spots were treated with 4 applications of fluoride varnish over a period of 1 month (once for week). Children with cavitated carious lesions were treated with ART. Children presenting advanced carious lesions with pulp involvement were sent to a Basic Healthcare Unit for specialized care.

SDM input parameters

Once all the data were collected, the following parameters were fed into the SDM:

- a. Population: 4000 inhabitants - the average number of people served by each FHS-OHT team (According to personal communication with Maringá oral health coordinator);
- b. Number of children aged up to 5 years in the area: 7% of the general population - estimated for the city of Maringá (data supplied by the Brazilian Statistics Institute);
- c. Mean dmft of the children aged up to 5 years in Paraná State: 2.4;^{3,20}
- d. Mean time required for 4 applications of fluoride varnish: 5 minutes;
- e. Mean time required for each ART restoration: 15 minutes;
- f. Cost of 4 applications of fluoride varnish: US\$ 0.179 (each) x 4 = US\$ 0.716 (Table 1);
- g. Cost of each ART restoration: US\$ 1.475 (Table 2).

Results

The material involved in the application of fluoride varnish is presented in Table 1, while the material for ART restorations is presented in Table 2.

Table 1. Cost calculation for the application of Fluoride Varnish.

Item	Price (unity)	Manufacturer	Use	Applications	Cost/ application
Fluoride Varnish 5%	U\$ 3.62 (15 ml)	S.S. White Artigos Dentários Ltda	100 µl/application	150	U\$ 0.005
Microbrush	U\$ 1.79 (100 unities)	Dentscare Ltda	1/application	100	U\$ 0.018
Cotton pellets	U\$ 0.34 (100 unities)	SS Plus do Brasil Ltda	5/children	20	U\$ 0.017
Surgical gloves	U\$ 4.74 (100 unities)	Descarpack Descartáveis do Brasil Ltda	1 pair/application	50	U\$ 0.095
Surgical Masks	U\$ 1.40 (50 unities)	Descarpack Descartáveis do Brasil Ltda	1/child	50	U\$ 0.028
Glengarry	U\$ 1.66 (100 unities)	Descarpack Descartáveis do Brasil Ltda	1/child	100	U\$ 0.017
Total cost/fluoride varnish application					U\$ 0.179

Source: Prices obtained from “Banco de Preços em Saúde” (<http://www.saude.gov.br/gestao-do-sus/economia-da-saude/banco-de-precos-em-saude>), and “Painel de Preços” (<http://paineldeprecos.planejamento.gov.br/>) website in November, 2019.

Table 2. Cost calculation for ART procedures using high-viscosity glass ionomer.

Item	Price (unity)	Manufacturer	Use	Applications	Cost
Glass ionomer	U\$ 73.75 (12.5 g)	Ketac Molar EasyMix, 3M ESPE	0.20 g/ART	62.5	U\$ 1.180
Cotton rolls	U\$ 0.34 (100 unities)	SS Plus do Brasil Ltda	5/children	20	U\$ 0.017
Dental Floss	U\$ 1.85 (500 m)	Hillo - Industria e Comercio Ltda	0.20 m/ART	2500	U\$ 0.001
Surgical masks	U\$ 1.40 (50 unities)	Descarpack Descartaveis do Brasil Ltda	1/ART	50	U\$ 0.028
Surgical gloves	U\$ 4.74 (100 unities)	Descarpack Descartaveis do Brasil Ltda	1 pair/ART	50	U\$ 0.095
Glengarry	U\$ 1.66 (100 unities)	Descarpack Descartaveis do Brasil Ltda	1 glengarry/child	100	U\$ 0.017
Polyacrylic acid conditioner 11.5%	U\$ 7.39 (10 ml)	D.C.M.A. Produtos Medicos e Odontologicos Ltda	0.05 ml/ART	200	U\$ 0.037
Calcium hydroxide (Hidro C)	U\$ 4.35 (10 g)	Dentsply Industria e Comercio Ltda	0.05 g/ART	600	U\$ 0.022
Solid vaseline	U\$ 7.40 (500 g)	Industria Farmaceutica Rioquímica Ltda	0.05 g/ART	10000	U\$ 0.001
Polyester matrix	50 unities U\$ 1.50	Preven Industria e Comercio de Produtos Odontologicos Eireli	1/ART	150	U\$ 0.005
Microbrush	100 unities U\$ 1.79	Dentscare Ltda	1/ART	100	U\$ 0.018
Carbon paper	12 unities U\$ 0.61	Preven Industria e Comercio de Produtos Odontologicos Eireli	1/ART	12	U\$ 0.050
Disposable coffee cups	U\$ 0.38 (100 unities)	TY Bortholin Comercial Ltda	1/ART	100	U\$ 0.004
Total cost/Art					U\$ 1.475

Source: Prices obtained from “Banco de Preços em Saúde” (<http://www.saude.gov.br/gestao-do-sus/economia-da-saude/banco-de-precos-em-saude>), and “Painel de Preços” (<http://paineldeprecos.planejamento.gov.br/>) website in November, 2019.

The SDM developed with Stella Architect software is illustrated in Figure 2. The SDM, together with instructions for use, is freely available at <https://exchange.iseesystems.com/public/karim/art-treatment>.

After inputting all the required parameters, the total cost for controlling caries in preschoolers within an area of 4000 inhabitants, conducted by the local OHT, was estimated by the SDM at US\$ 698.00. This total amount included 4 applications of fluoride

varnish, and the conduction of ART restorations as required. The clinical time estimated for the application of fluoride varnish was 14 hours, while for ART restorations it was 98 hours (Figure 3).

Discussion

This study presents an SDM that was developed to estimate the costs and clinical hours required to control the evolution of carious lesions in preschool

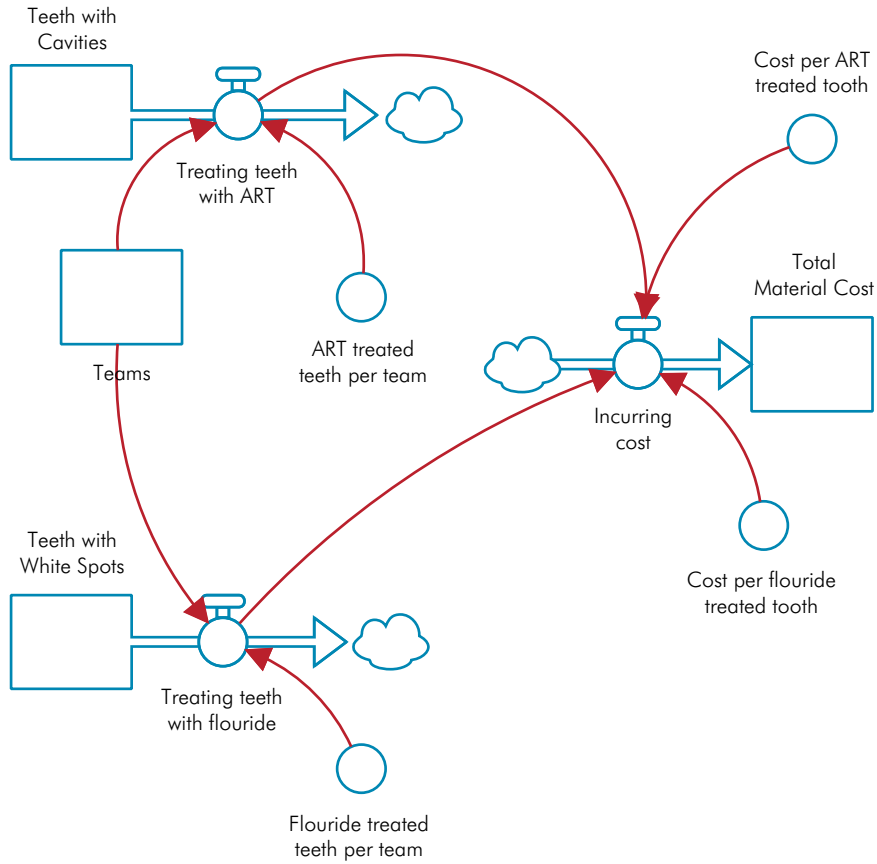


Figure 2. System Dynamics Model to estimate the cost and clinical hours required to control dental caries in preschoolers conducted by a local oral health team.

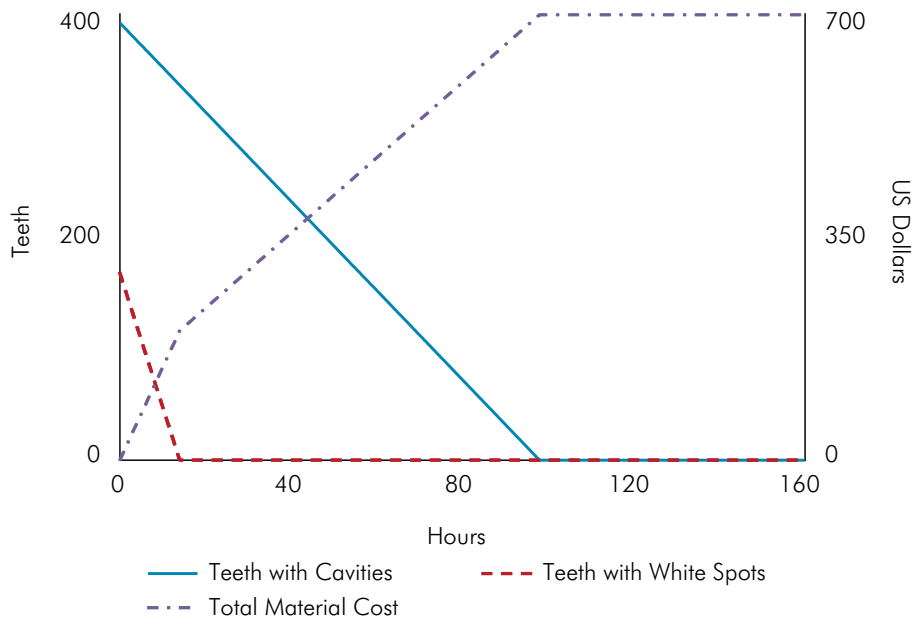


Figure 3. System Dynamics Model demonstrating the relationship between clinical time and cost required to control dental caries conducted by a local oral health team.

children within a geographical area served by an OHT in the city of Maringá, Brazil. The results of this study demonstrated that making use of preventive and curative actions at the early stages of dental caries does not necessarily involve large investments or clinical time, as the total cost for controlling caries in preschoolers estimated by the SDM was US\$ 698.00.

The impact of preventive programs for the control and reduction of caries has been widely recognized.¹⁷ However, preventive programs alone may have limited effect on more advanced stages of dental caries. In a previous study, SDM was used to evaluate the relative effect and cost of six different types of ECC treatment: application of fluoride; limiting cariogenic bacterial transmission; use of xylitol; clinical treatment; motivational interviewing; and a combination of these. The authors observed that combined interventions showed the greatest potential for the reduction of carious lesions, considering that interventions on children at the highest risk resulted in the highest return on the investment.¹⁷

Apart from preventive measures, alternative strategies have been developed to improve the oral health of children with the adoption of curative treatments whenever required.²¹ Two different interventions on carious lesions were considered in the present study as part of a strategy to control the disease in preschool children. Teeth presenting white spots were treated with fluoride varnish, while cavitated carious lesions without pulp involvement were treated with ART. These interventions were performed by an OHT composed by a dentist, an oral health technician, and an oral health assistant. The OHT works within a designated geographical area, so that the most vulnerable populations can have access to oral care. This strategy controls the disease at lower costs and maximizes clinical time. In the present study, the children were treated in their own school in a specially prepared room under natural lighting during OHT visits. Because of the familiar surroundings, children feel minor or no stress and anxiety, facilitating treatment.^{22,23}

The efficacy of fluoride varnish applied on teeth presenting white spots has been well established. The application of fluoride varnish promotes the

remineralization process and control the evolution of caries.²⁴ Its application is simple, fast, and, as observed in the present study, quite inexpensive. When applied at early stages, it can substantially assist in the preservation of the dentition in the long term. When cavitated carious lesions are present at an early age, also known as “early childhood caries”, the treatment may be made more difficult because of the lack of cooperation from the child, sometimes requiring the use of general anesthesia.²⁵ ART is a minimally invasive technique that preserves healthy tooth structure by selectively removing carious tissues with hand instruments.²⁶ Later, cavities are restored with glass ionomer cement (GIC), preventing the exposure of the pulp. The procedure arrests the evolution of dental caries and prevents the need for canal filling and extractions, preserving the primary dentition until exfoliation.²² Studies have demonstrated good survival/success rates of ART restorations in primary teeth^{27,28} and also in the permanent dentition.^{29,30} ART has a broad social impact, reducing costs and clinical time.^{31,32} It has been described as an economical and effective method to prevent dental caries progression in vulnerable populations.³³ Because it only uses hand instruments, ART does not require the infrastructure of a dental office and can be performed in locations where conventional treatment is not possible or access is precarious. Moreover, because the procedure rarely causes pain, anesthesia is not required.²³

In another study of our group³⁴, System Dynamic modeling was useful to simulate the impact of preventive and educational approaches on the maintenance of people’s teeth throughout their lives. This study demonstrated that the acquisition of health habits through educational approaches could result in the increase of number of people with no tooth loss, improving quality of life.

As observed in the present study, the SDM can be used to justify preventive policies within an existing system. SDM can show that certain interventions may not necessarily involve excessive cost or be time-consuming. One important limitation, however, concerns the fact that even small SDMs, such as the one presented here, are not simple to develop. It demands a very careful and systematic analysis

of the problems targeted and the support of experts. Only after extensive trial and error, the final version of the SDM responded as expected. Nonetheless, once developed, the model in the present study may be used in different locations with people needing treatment, with similar problems by simply inputting that location's own data.

Conclusion

SDM can represent a powerful tool in Dentistry with the potential to assist decision making by measuring the material and human resources required

to prevent and control dental caries at an early age. Early diagnosis and treatment of dental caries lesions with the application of fluoride varnish and ART treatment on preschool children has been shown to be a viable strategy without incurring high costs.

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