Reflections on Assumptions for a Simulation Model of Dental Caries Prevention Planning in a Primary School

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ABSTRACT

The discrete event simulation method is commonly used to support decision-making in healthcare management. It is also used in planning the prevention of tooth decay in schools. Its usefulness largely depends on the concept of the model, which reproduces a fragment of reality along with the assumptions made. The aim of this paper is to discuss particular important modeling issues, which we faced, while developing a discrete event simulation model to support decision making in caries prevention planning in a sample primary school in one of the cities in the South-West Poland. We present reflections on the assumptions for the discrete event simulation model. The first stage of the simulation study confirms the relevance of the analysis of these assumptions and that their choice was appropriate. Therefore, the developed model may be the basis for further research and, as a result, be a tool to support management in planning the prevention of tooth decay in primary schools in Poland.

INTRODUCTION

The problem of tooth decay is considered a disease of the 21st century and affects more than half of the world's population (WHO, 2017). It is a relatively preventable disease, yet it is a big problem among the population. Therefore, prevention, properly planned and carried out from the earliest years of life, plays an important role. To take preventive action, a number of decisions related to their planning must be made. This requires financial, material and human resources, each of which is limited. So special care must be taken in planning the use of these resources to achieve the goal of preventing the spread of tooth decay. Managing processes in which people are involved and their decisions, behaviors, and health predispositions requires an approach that can take all these aspects into account. Thus, mapping health care systems is challenging and the reliability of the models developed can have a significant impact on management decisions.

One method that can be used to study preventive service delivery systems is simulation modeling. This method has been used for years to support management in health care, both in relation to medical issues and to support decision-making processes. One of the key steps in all simulation studies is *Model conceptualization* (Banks Jerry et al. 2010). The assumptions formulated within every research are specific to the modeled system, its details, and the individual approach to the problem. Thus, it is not possible to write down universal rules for model conceptualization.

This paper focuses on the issue of formulating assumptions within the discrete event simulation (DES) approach to plan preventive care for dental caries in primary schools. The objective of this paper is to discuss particular important issues that we faced while developing a discrete event simulation model to support decision-making in caries prevention planning in a sample primary school in one of the cities in South-West Poland. The remainder of this paper is organized as follows. The next section describes the literature background. Subsequently, the main assumptions formulated in the conceptualization stage are presented. Then the simulation model and its verification and validation are discussed. Finally, conclusions and future research steps are presented.

LITERATURE BACKGROUND

Simulation methods are most often categorized according to 4 categories: discrete event simulation (DES), agent-based simulation (ABS), system dynamics (SD), or Monte Carlo (MC) (Brailsford et al. 2009). These methods are used in healthcare research (Katsaliaki and Mustafee, 2011). Different application areas may be distinguished; apart from health policy, simulation methods are being used in diagnosis and improvement, forecasting, medical decisions and threats (Mielczarek, 2014). In the field of dental caries prevention, examples of their use can also be found, but such studies are few and there is still a wide gap to fill.

In the area of simulation methods used in the context of research that addresses caries prevention management issues, papers using each of the four simulation approaches may be found. The ABS was a good method to model mechanisms affecting the occurrence of caries and to verify the effects of preventive interventions (Heaton et al. 2020). To determine the optimal combinations of staffing levels and sealant stations for school-based sealant programs, the DES method was chosen (Scherrer et al. 2007). The SD method was used to examine the relationships between dental caries status under different policy options (Urwannachotima et al. 2019) and to investigate the complex interrelationships among sugar-sweetened

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beverage tax, sugar consumption and dental caries (Urwannachotima et al. 2020). Using MC, the lifelong costs of caries with and without fluoride use were modeled (Johhnson et al. 2019) and the possible financial effects and impact on caries prevention of receiving fluoride varnish were estimated (Scherrer and Naavaal, 2019).

Thus, the utility of simulation methods in supporting management in caries prevention has already been noted. Each of the above-mentioned simulation methods is an advanced approach, the application of which requires knowledge of many elements from different areas. Undoubtedly, one of them is the real system modeled and the dependencies that enter into it.

PROCESS OF PROVIDING PREVENTIVE SERVICES

The process of providing preventive services from the beginning to the end of primary school was modelled according to the framework presented in Figure 1.

After starting school, the pupil is placed in a kindergarten (*n*=0). During the school year measured in days (*d*), preventive services are provided. When the school year ends, she or he is placed in the next grade to begin the new school year (*n*=*n*+1). At the end of the last grade (*n*=8), the pupil leaves the school. The watch symbols indicate the passage of time.

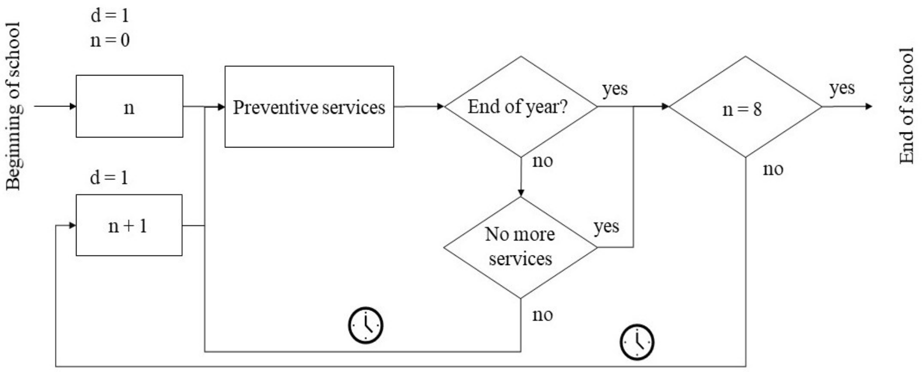

Figure 1: Flowchart describing preventive dental caries services from start of schooling through completion (*d*-day; *n*-grade)

Preventive services are provided to pupils during their education. Primary school education lasts 9 years, from kindergarten to grade 8. During this period, pupils are supposed to receive preventive care for caries. Preventive care in schools is financed by the state, but the way it is carried out is the responsibility of the directors of each educational institution. Preventive services include educational talk, fluoridation, dental check-up, and sealing of the first molars.

MAIN ASSUMPTIONS FORMULATED DURING THE CONCEPTUALIZATION PHASE

Assumptions relating to simulation parameters

Simulation parameters are a part of every simulation research. The main problems are related to the values that should be applied. How should a system be observed, whether we can collect statistics right away, whether we need a warm-up period, or how many replications should be conducted?

In the case of the system of providing preventive services in primary school, observations can be carried out during the entire education or particular periods of education, for example, depending on the age of the pupils.

The system we present is observed for 9 years. This is a period of primary education in Polish schools. Before statistics can begin to be collected, all classes in the school must be filled with pupils. Therefore, the warm-up period is also equal to 9 years. Minutes are the base units of simulation because the duration of preventive services is usually a few minutes. The number of replications is 5.

Assumptions related to the inflow of pupils

Under the DES approach, pupils are represented in the model by entities that move through a system of caries prevention services provided at school. In the inflow of pupils section, we can consider how they are expected to flow into the model and which of their characteristics are relevant to the research. Moreover, we must determine whether to account for migration of pupils between classes or between schools and whether to assume absences, which may be due to a variety of reasons.

Should we model the individual inflow of pupils to a school or the inflow of whole classes? Modeling the inflow of pupils as individuals involves the subsequent need to group them into classes because in school, pupils attend the class with which they spend the most time and within which they are directed to the various services that take place in school. In contrast, modeling this inflow as a class involves separating classes to attribute the individual indicators changes and within certain services that are done individually.

This problem was solved by analyzing the use of two options. As described earlier, each has its pros and cons. It was decided to model the inflow of pupils within classes. Every year there are five incoming classes, the size of which is 20 which is determined by average number of pupils per class from Statistics Poland (SP). Furthermore, the model did not assume changes in the number of pupils due to migration or absenteeism. It was assumed that all pupils were in a given school from the beginning to the end and that they were always present during preventive services.

Is it important to include the gender and age of the pupils in the model? Within the pupils' characteristics that can be modeled, the primary ones include gender and age. It is important to consider whether there are significant differences between genders that may be relevant for research. On the other hand, as for age, it is known that there are as many different birth dates as there are pupils in a school. In a given class, there may be differences in the years of the pupils. In addition, there are times when pupils start school at an earlier age. So, as with gender, is it necessary to account for such differences or is it necessary to assume equal age? We should also consider how detailed we want to analyze the demographics of the community. To decide whether to include gender, a dmft indicator values (*dmft: decayed, missing, and filled teeth*) were compared across the study region. These indicators are commonly used in dentistry to assess dental health. The symbol dmft is used for prmiary teeth and the DMFT for permanent teeth. The higher the index value, the more advanced the caries.

The dmft index for pupils at 6 years of age in the study region was 2.89±2.90 and 4.32±3.36 for women and men, respectively. At 7 years of age, the index values were 5.43±3.28 and 5.41±3.24 for women and men, respectively (Olczak-Kowalczyk et al. 2021).

By analyzing the data on the problem of dental caries and based on the reviewed literature, it was determined that gender would not be distinguished in the pupils. Although at age 6 the gender gap in indicators values was noticeable, by age 7 this difference had already disappeared.

Regarding the age of the pupils, it was assumed that the pupils start school at the age of 6 and are one year older in each subsequent grade until they reach the age of 14 in the last grade. We did not account for differences due to different birth dates.

Assumptions related to the structure of the school year

Within DES, we can see the dynamic changes that occur at specific points in time. Pupils start school, attend classes, and receive preventive services. But during the course of their education, there are days off, sometimes regular like weekends, and sometimes less regular like certain holidays or winter breaks. This raised the question how to model the structure of the school year so that it reflects reality as well as possible and is a universal one.

In Polish primary schools, pupils attend school from September to June, followed by a vacation period. During the school months, pupils have Saturdays and Sundays off, public holidays, two breaks for Easter and Christmas, and two weeks of winter holidays. The most detailed approach could be to write a calendar with school days and holidays for each simulated year. However, despite the differences that exist between each calendar, they are scheduled according to the same rules.

As part of making assumptions about the structure of the school year, we conducted detailed analyses of school calendars from 2011 to 2021. In these years, the number of school days ranged from 183 to 188, the winter break was always 2 weeks, the Christmas holiday break was 6 to 9 days, and the Easter holiday break was always 4 days. So, in the end, the model assumes the sample calendar corresponding to the 2021/2022 school year. It assumes 187 school days, a Christmas holiday break of 7 days, an Easter holiday break equal to 4 days, a two-week winter break, and 6 working days off due to public holidays. These components plus weekends add up to a school year that runs from September to June.

Assumptions relating to key attributes

Attributes in DES models are assigned to entities (e.g. pupils) and various characteristics can be stored in them. The question often arises as to which attributes are critical for the system being modeled and when to update them.

Regarding the process of providing preventive services, pupils may be assigned a number of attributes. Some of these may relate to basic pupils' characteristics such as age, class attended or year of school entry. Additionally, values for indicators, such as dmft and DMFT, related to oral health status can be recorded for a given pupil.

In our study, in addition to the attributes that characterize pupils, related to preventive services or defined for the correct performance of the model, among the key attributes are the dmft and DMFT indicators. The processes involved in changing oral health are continuous processes, but in the discrete model, the values of the relevant indicators are read once a year at the end of the school year. Each pupil is assigned an initial dmft and DMFT index value at the age of 6. The values of these indicators are updated at the end of each year according to the normal distributions assumed after reviewing the actual data (Olczak-Kowalczyk et al. 2021).

Depending on the sum of the dmft and DMFT indicators, one of three Dental Caries Status (DCS) can be assigned to each pupil: good, moderate, and bad (Table 1).

Table 1: Three states of DCS depending on the number of teeth with caries. The values in the table give the total number of primary and permanent teeth with caries

DCS	dmft +DMFT
Good	0
Moderate	1-3
Bad	4 and more

Caries disease progression is reflected in the model by random distributions that correspond to actual data (Table 2). For dmft, the index value increases between the ages of 6 and 7 and then decreases by the age of 12. In contrast, for DMFT, it increases with each additional year.

Table 2: Change in the dmft and DMFT indicators

Indicator	Initial condition	6-7 years change	7-10 years change	10-11* and 10-12** years change	12-15 years change
dmft	3.65 ±3.21	1.77 ±0.37	3.8 ±0.27	1.62 ±0.19	-
DMFT	0.09 ±0.47	0.52 ±0.08	1.27 ±0.18	1.72 ±0.22	1.82 ±0.40
* primary teeth ** permanent teeth					

Source: Own elaboration based on real data (Olczak-Kowalczyk et al. 2021)

Assumptions related to the realization of preventive services

As part of preventive services, we include dental check-ups and seals of the first permanent molars in the model. The biggest challenge in this area was to model the impact of individual preventive services on pupils' oral health. A second challenge was to develop a level of detail that would be sufficient for management inference and medically correct. At this point, it is important to mention that the purpose of the model is not to predict the health status of pupils or to examine the impact of preventive services on this health status. The model is intended to support management related to preventive care planning. This stage examines how sealing results in a reduction in the average DMFT during subsequent school years.

The ideal situation would be to conduct clinical trials that focus on exactly the aspects needed in research. And then use the results obtained in further studies. Unfortunately, this is very difficult to do in practice, and other solutions should be sought. One of them may be to start cooperation with medical centers to conduct joint research. Or, if such collaboration is not possible, use already published research in the desired area.

In the present study, it is assumed that dental check-ups are performed twice a year. It is intended to provide caregivers for pupils with information on treatment needs, but in our study we do not address these aspects. Furthermore, the pupils' molars are sealed at the age of 6 years, when the first molars erupt. Based on the literature, we assumed that seal reduces the risk of caries by 79% (Wright et al. 2016).

SIMULATION MODEL

The purpose of the first stage of the conducted research was to check a simulation model for one type of preventive services provided in a sample primary school located in South-West Poland.

The authorial model based on the assumptions presented was built in Arena v16.1 (Rockwell Software), following the DES methodology. As preventive services in the first stage of the study, we included dental check-ups and sealing of the first permanent molars. The output measure was the average DMFT index at the end of primary education.

The model consists of four main components: time control, inflow of pupils, preventive services, and update of indicators. The time control section is responsible for controlling the passage of time by counting days and consecutive years. Then, in the other elements of the model, the pupils are provided with preventive services or promoted to the next grade. In the inflow of pupils section, we generate five streams of entities, one for each of the five parallel classes that come into the school. The school should have 45 classes in total, five in each of the nine-year classes. In the section related to indicator updates, pupils have their dmft and DMFT values recalculated; this occurs at the end of each school year. Figure 2 shows dental examinations and the sealing section. Table 3 presents the key attributes.

Table 3: Key attributes used in the DES model

Name of attrbiute	Description
Beginning	It provides the year of the beginning of school
Age	It provides information on the age of a pupil.
$dmft_n$	It stores information on a number of decayed, missing and filled primary teeth of a pupil in the *n* year of education (n = 1,...,9).
$DMFT_n$	It stores information on a number of decayed, missing and filled permanent teeth of a pupil in the *n* year of education (n = 1,...,9).
Section ABCDE	It provides one of five school sections to which a pupil is assigned. We modeled a primary school that has five sections in one year. Each pupil is assigned letter A, B, C, D, or E.
Section number	It shows one of nine sections to which a pupil is assigned. We modeled a primary school where the pupils learn for 9 years. The number of sections changes according to the year of education.
School section	It is a combination of the *Section ABCDE* and the *Section number*. It stores all-encompassing information about the section that a pupil attends.
Section size	It stores information on a number of pupils in a school section.

MODEL VERIFICATION AND VALIDATION

The assumptions were consulted with a dentist who confirmed their accuracy. It was also checked whether the average values of the dmft and DMFT indicators obtained in the model correspond to the average values of these indicators in reality (Table 4).

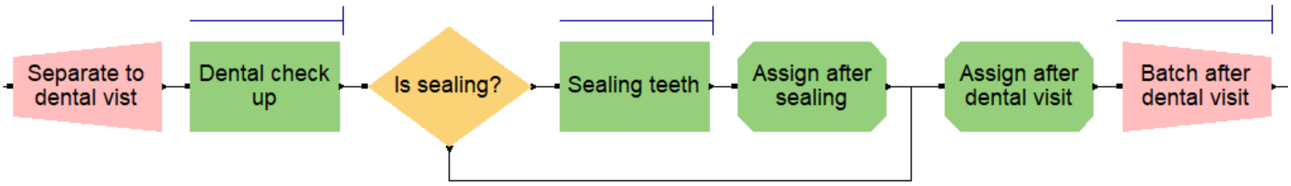

Figure 2: An excerpt from the model presenting the dental check-up and tooth sealing section

The averages obtained allowed for further verification to be performed for one type of preventive service, which is sealing the first permanent molars.

Table 4: Comparison of average values of actual the dmft and DMFT indicators along with standard deviation (±) and those obtained in 5 replications of a simulation along with confidence interval (CI)

Indicator	Data	Age			
		6	7	10	12
dmft	Reality	3.65 ±3.21	5.42 ±3.25	1.62 ±1.88	-
dmft	Simulation	3.52 (0.95 CI, 3.05-4)	5.22 (0.95 CI, 4.73-5.72)	1.7 (0.95 CI, 1.21-2.19)	-
DMFT	Reality	0.09 ±0.47	0.61 ±1.12	1.88 ±1.63	3.6 ±2.74
DMFT	Simulation	0.01 (0.95CI, -0.02,0.05)	0.22 (0.95 CI, 0.14-0.3)	1.39 (0.95 CI, 1.3-1.48)	3.10 (0.95 CI, 3.02-3.17)

We conducted two simulations. The first, in which pupils were not provided with sealants, and the second, in which sealants reduced the risk of caries by 79% (see Assumptions relating to the realization of preventive services). Five replications were performed. The length of one replication was 18 years, with the first 9 warming up the model and the next 9 collecting statistics. The results are presented for pupils who started primary school in the same year (Figure 3).

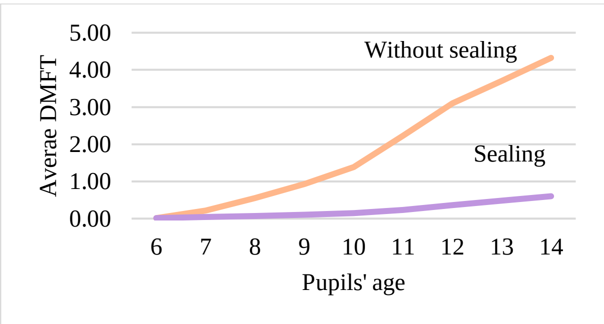

Figure 3: DMFT value in 100 pupils who started school at the same time, with and without sealing during primary education - average of 5 replications

In Figure 3, it may be notice that without sealing, the average number of DMFT for pupils increased with age until it reached a value greater than 4 at age 14. In contrast, the use of sealant resulted in the average number of DMFT less than 1 over the years.

CONCLUSIONS

Caries prevention care in Polish schools is not provided at the level it should be. This may be due to limited resources that can be used in its implementation or lack of proper planning. Caries prevention care planning is a comprehensive and complex issue influenced by many factors and requires the use of advanced decision support tools such as DES. The aim of this paper was to discuss issues, which we faced, while developing the DES model to support decision making in caries prevention planning. The aim was achieved and a number of key assumptions were defined and carefully analyzed. To test the accuracy of the constructed assumptions, the DES model was built and checked for one type of preventive benefit. Our model enables simulating a system for providing caries prevention services in primary schools and its impact on pupils' oral health status. The model developed in this research is designed to support management related to the planning of preventive care. It is not a model to predict the health status of pupils. Depending on the specific focus of the research, it can be developed in a variety of ways, providing a universal tool for the development of adequate policy for the provision of caries prevention services.

In this paper, we have presented the key assumptions and formulation issues that we faced in the first stage of the research. The model has been validated and the results of that validation are presented for the potential effects of a single preventive service. Comprehensive verification and validation are planned for the next stage of the research. The results obtained are acceptable and promising for further research that will move in the direction of including more preventive services in different regions. In addition to dental check-ups and sealing, fluoridation and education will be included. By extending the research to different regions, it is planned to take into account the characteristics of the population living in these regions, for example: education level, poverty and access to medical services. The final model will be able to examine the effectiveness of different configurations of more preventive services and compare them between different regions. Effectiveness will be understood as a reduction to 0 in the number of pupils who graduate with bad DCS. At this stage of the study, the validity of the assumptions has been checked first and foremost, making it possible to move on to the next stage of the study.

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