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Modeling Nurse Time for School Health Service using System Dynamics

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Abstract*: One of the national primary health care services in Malaysia is school health care. This care is very crucial as it ensures that, countrywide, the health of students from the age of five to fifteen is in a good condition. In Malaysia, nurses hold a major responsibility for delivering the school health service. However, there is no solid research investigating the nursing time required to deliver school health services. This paper presents a system dynamics model representing the specific school health services delivered by nurses. System Dynamics is a computer-aided approach to policy analysis and design. In this paper, the system dynamics model are represented by several causal loop diagrams which covers all the school health activities and is able to determine the projected total nurse time required in delivering the service. The baseline simulation result of the nurse time required for delivering school health services is about 1080000 hours in year 2030, which is equivalent to 680 full time equivalent (FTE) nurses. Furthermore, various what-if analyses are tested with the model, as it is important for policy makers to investigate various scenarios for an effective decision-making process. In other words, the theme of the study is to understand the implication of the changes in school population size and the modification of certain activities in the school health program on the nurse time spent delivering school health service by developing a dedicated forecasting system dynamics model for school health. The time horizon for the forecasting is from 2018 until 2030.

Keywords: Modeling, Simulation, School Health, System Dynamics, Nurse Time, Forecasting.

I. INTRODUCTION

In the healthcare system, Primary Health Care (PHC) is the front line in the community, supported by secondary and tertiary care [1], [2]. It emphasizes health care services which include health promotion, management of illness, and injury prevention as well as personal care [3]. According to the Institute of Medicine, there are five components that define 'ideal' primary care: (1) integration within the larger medical system; (2) accessibility for the patient; (3) serviced by clinicians who are accountable for addressing a large majority of personal health care needs; (4) built on sustained partnerships with patients; and (5) practiced in the context of family and community [4].

One of the primary care services in Malaysia is School Health Care [5][6] which is accessible to the primary and secondary school students nationwide. According to [7], the school health care in Malaysia can be divided into three main categories: school health service, school dental service, and, finally, school environmental health service. The school health service has three objectives. The first objective is to ensure that the health of school children is maintained at the most optimum level by providing health promotion as well as disease prevention, treatment, and referral. The second objective is to detect any health problems that can cause a delay in academic achievement among the school children, as well as to offer early referral, thus enabling early intervention and placement for students who need to go into a special education system. Finally, the third objective is to encourage community involvement in ensuring the school is a safe and healthy institution, which will enable effective learning. Based on the listed objectives, it can be seen that the government under the responsibility of the Ministry of Health (MOH) Malaysia is providing an holistic health service to ensure optimum health care among school children by providing scheduled visits to both primary and secondary schools. Nurses are one of the primary health care providers that deliver the school health services [8], [9]. In order to ensure that all students have full access to the school health services, the number of nurses required for this particular service should be determined carefully for current need as well as for future needs. Forecasting in terms of nurse time is very crucial when it comes to determining the number of nurses required for the future [10]–[12]. It must be noted that failing to determine the number of nurses (or the total nurse time) required for the school health service will risk the health of the children as nurses are the major health care provider for the school health service. Obviously, there are negative consequences associated with the risks, as the children are our country's future.

In order to determine the number of nurses required to provide the school health service, the total nursing time required for this specific service must be obtained. There are numerous studies that investigate nursing time [13]–[15]. However, there is no study dedicated to determining the total nursing time required for the school health service [16].

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Therefore, the purpose of this paper is to fill in the gap by investigating the total nursing time for the school health service as well as forecasting the total nursing time required in the future. The innovation in this paper is to investigate the total nursing time for delivering the specific school health service by developing school health nursing time model using system dynamics approach.

System dynamics is a powerful approach to understand and model the behavior of complex system over time in which it has been used widely in health care domain [17]–[21]. Thus, the motivation that drives this paper is to disseminate the knowledge of the innovation for proper health human resource planning, as time is often regarded as cost and it is one the significant resources.

Section 2 of this paper illustrates the system dynamics model of nursing time for the school health service. It firstly provides the detail of each sub-model representing each school health activity in every sub-section. The section then provides an overview of the dynamics at a higher-level perspective by taking into account the interaction between total nursing time required for school health, full time equivalent (FTE) nurses required and the gap between supply of nurses and required nurses. The result and discussion for the forecast nursing time and FTE nurses required for school health are presented in Section 3. The conclusion of this paper is provided in Section 4 where the significance of the forecast model using system dynamics is highlighted.

II. THE NURSE SERVICE TIME PROJECTION MODEL FOR THE SCHOOL HEALTH SERVICE

In general, there are a total of five activities covered by the nurses under the school health service. The activities are basic health education, physical examination, visual assessment, immunization, and referral writing. These activities focus on the health of students from pre-school (age 5 and 6), primary school (year 1 and year 6 only) and secondary school (form 1 female and form 3). Table I illustrates the school health activities delivered to the focus groups. In this paper, there are five focus groups of school children that receive school health service. Nurses are required to perform activities according to the focus group. For example, nurses need to give basic health education, perform physical examination, give immunization and write referral letter for focus group form 3 (age 15).

Table- I The school health activities and their focus groups

Activities/ Focus group	Basic health education	Physical examination	Visual assessment	Immunization	Referral letter writing
Pre-school (age 5 and 6)	/	/			/
Year 1 (age 7)	/	/	/	/	/
Year 6 (age 12)	/	/	/		/
Female form 1 (age 13)	/	/		/	
Form 3 (age 15)	/	/		/	/

As a general idea, the total nursing time to perform each activity for the entire related focus group need to be firstly determined. For example, by referring to Table I, the total nursing time to perform visual assessment is obtained by adding both the nurse time of visual assessment for year 1 and year 6. In order to use the system dynamics approach, the interaction between all the factors or elements that affect the total nursing time for the school health service is investigated. Once the dynamics of the interaction among all of these factors or elements are obtained, the causal loop diagram can be used to represent the relationship among the elements of each activity in the school health service. In general, there are two types of causal loop diagram to represent the cause and effects: the open loop and the closed loop. According to [22], [23], open loop refers to a linear chain of cause and effect in which it does not close back on itself, while closed loop refers to a circular chain of causes and effects. In this paper, open loop diagram is used to describe each sub-model representing each school health activity while the close loop diagram is used to describe the higher-level perspective of school health model.

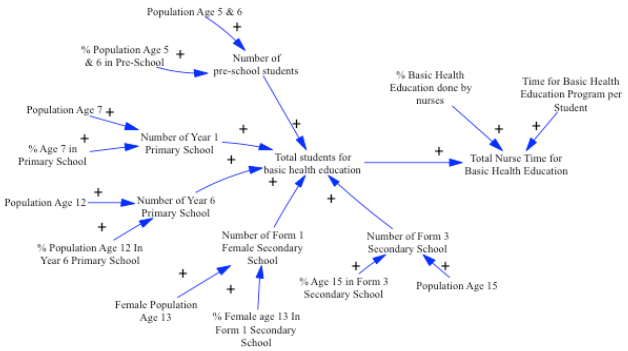

Fig. 1 The open loop diagram for total nurse time to conduct the basic health education

Both type of diagram which represent the details of the activities as well as how the total nurse time spent on the school health service is accounted for, are described in the following sub-sections. The model is developed in the system dynamics simulation software. Some of the selected variables for the school health service model and how it is coded into Vensim Simulation software are presented in Table III in the Appendix. In this paper, the population of each focus group, the nursing time for each activity for every student, the percentage of shared responsibility for the healthcare providers, and the percentage of students who require the services, as well as the FTE for nurses are among the significant factors identified in this study. The interaction between all these factors are described in the causal loop diagrams as presented in following subsections.

A. Total nurse time for basic health education

All five focus groups are given basic health education by the nurses. Hence, the number of students for these focus groups needs to be determined by considering the age group population in the country and the percentage of the age group in the school. This sub-model firstly determines the total number of students for basic health education followed by the total nurse time for this activity.

Fig. 2 illustrates the open loop diagram to determine the total nurse time for basic health education. The '+' sign at the arrow indicates the 'positive' effects. For example, an increase in total students for basic health education will increase the total nurse time for basic health education

B. Total nurse time for physical examination

Besides basic health education, nurses also spend time on a physical examination of all students. For each focus group, this examination has a different duration. Hence, the process to determine the nurse time required to conduct the physical examination is carried out separately for each focus group. Once all the nurse time for the physical examination from all the focus groups has been determined, the total nurse time required to conduct the physical examination is obtained. Fig. 2 illustrates the open loop diagram to determine the total time required to conduct the physical examination.

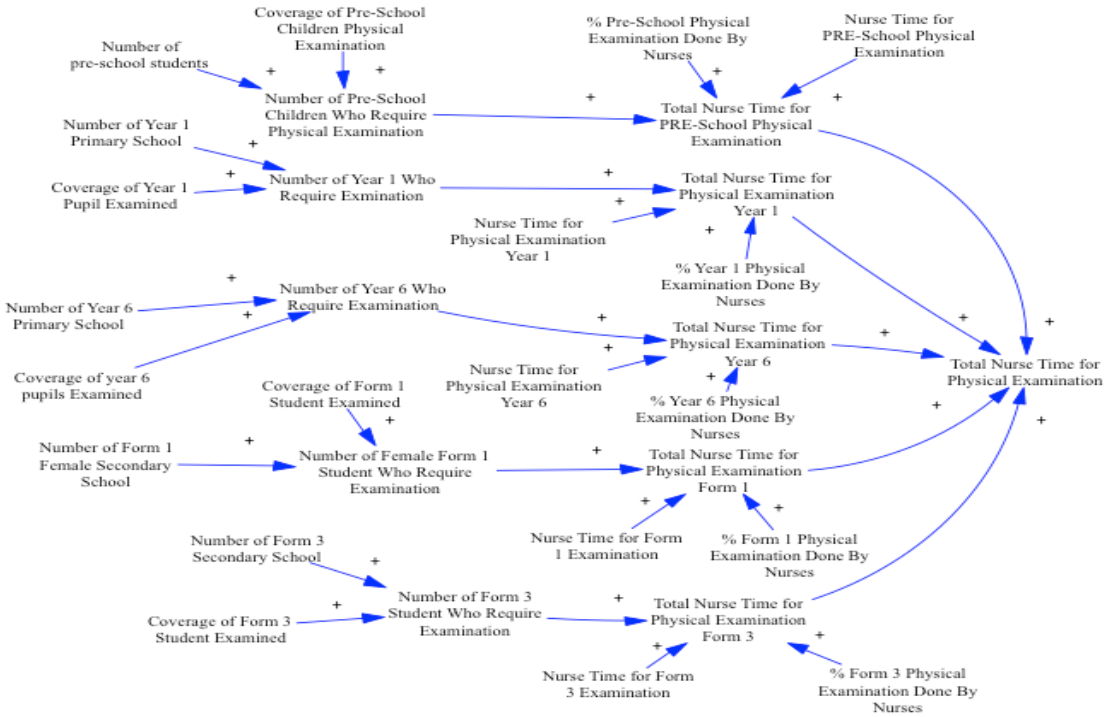

Fig. 2 The open loop diagram for total nurse time to conduct the physical examination

C. Total nurse time for visual examination

The third activity in the school health service is visual examination. Therefore, the third sub-model determines the total nurse time for this examination. This is achieved by identifying the number of students who require a visual examination followed by the total time for this examination separately for year 1 and year 6 students. The total nurse times for these two focus groups are then added together, as illustrated in Fig. 3.

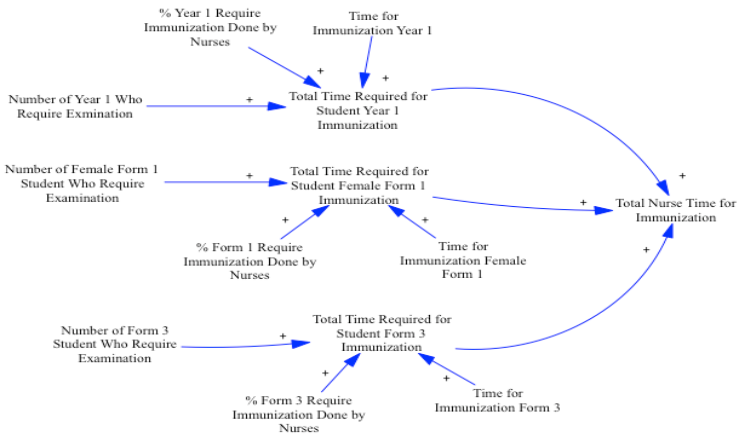

Fig. 3 The open loop diagram for total nurse time to conduct the immunization

D. Total nurse time for the immunization program

For the immunization program, only year 1 primary school students, female form 1 secondary school students and form 3 secondary school students are involved. Therefore, the fourth sub-model determines the total nurse time for student immunization for only three focus groups. This is achieved by identifying the number of students who require immunization separately for year 1, female form 1 and form 3 students. This is followed by determining the total nurse time required to carry out this immunization, as illustrated in Fig.4.

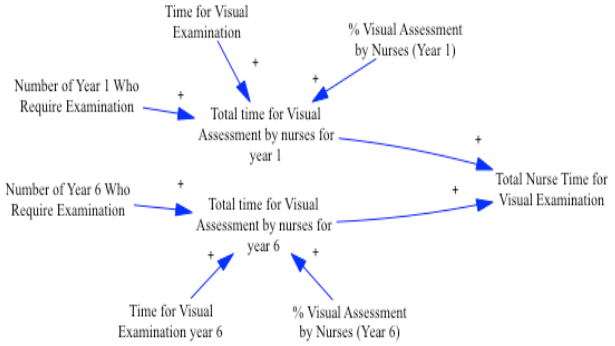

Fig. 4 The open loop diagram for total nurse time to conduct the visual assessment

Total nurse time for referral letter writing

Finally, nurses also spend time writing referral letters for those students who require referral to the doctor. The referral letter applies to pre-school children, year 1 and year 6 primary school, and form 3 secondary school students.

Fig. 5 illustrates the open loop diagram to determine the total time spent for referral writing.

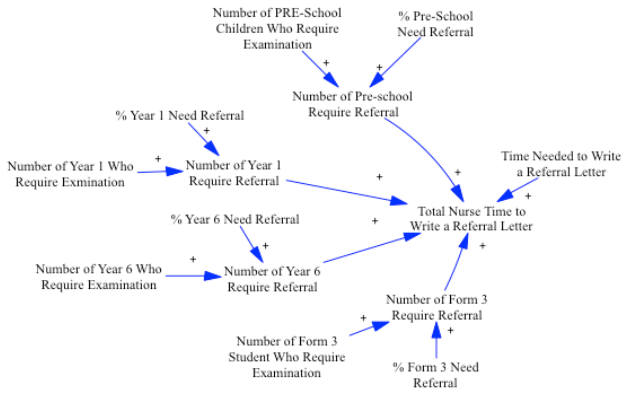

Fig. 4 The open loop diagram for total nurse time spent writing referral letters

E. Total nurse time for school health and its associated higher-level perspective

Fig. 6 illustrates the causal loop diagram that is very useful to represent the dynamics of the higher-level perspective for school health services. The interaction of total nurse time for every activity and the entire total nurse time for school health is also captured in Fig. 6. Again, the '+' sign at the arrow from every activity indicates the 'positive' effects. For example, an increase in total nurse time for physical examination will increase the total nurse time required for school health.

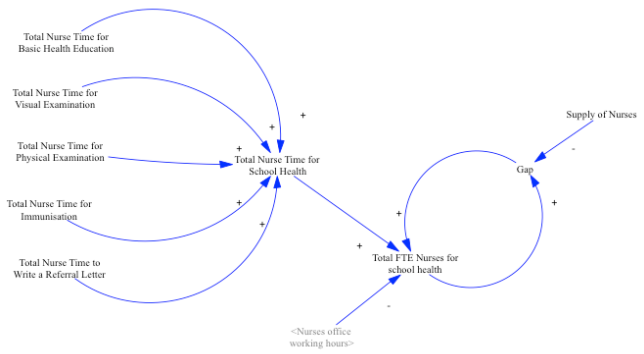

Fig. 5 The higher-level perspective of school health service presented by the closed loop diagram

Therefore, the total nurse service time required to carry out the school health program is calculated by adding together all the time spent on these activities, as described in (1)

$$\begin{aligned}\text{Total Nurse Time for School Health} &= \text{Total Nurse Time for Basic Health Education} + \text{Total Nurse Time for Visual Examination} \\ &+ \text{Total Nurse Time for Physical Examination} + \text{Total Nurse Time for Immunisation} \\ &+ \text{Total Nurse Time to Write Referral}\end{aligned} \tag{1}$$

The FTE nurses required for school health is obtained using the following equation:

$$\text{Total FTE Nurses for School Health} = \frac{\text{Total Nurse Time for School Health}}{\text{Nurse Office Working Hours}} \tag{2}$$

An increase to the total nurse time for school health leads to an increase to the total FTE nurses required for school health. In this paper, the difference between the total required nurses and the supply of nurses is defined as the gap. The gap is obtained using the following equation:

$$\text{Gap} = \text{Total FTE Nurses Required for School Health} - \text{Total Supply of Nurses} \tag{3}$$

The gap will increase if the total FTE nurses required for school health increases. On the other hand, if the supply of nurses increases, the gap will decrease. This is a 'negative' effect as indicated by the '-' sign at the arrow. The higher-level causal loop diagram in Fig. 6 is a closed loop diagram. To be specific, the closed loop diagram in this paper is of a reinforcing type. It must be noted, in this paper, the equation of the gap is presented as a reference for future work when integrating with total supply of nurses. Hence, there will be no result for the gap in this paper since the major aim of this paper is to determine the total nurse time for delivering school health service only.

III. RESULT AND DISCUSSION

The model of required total nurse time for the school health program is validated using a subjective approach, which is face validation. According to [24], an individual with the appropriate knowledge about the system being investigated is needed for validation in order to determine whether the developed model and its behavior are reasonable. In this research, the face validation is conducted continuously with personnel from the MOH (the nurse division and the planning division).

This includes examining the flow in delivering each service to the respective age group in the model. In addition, the nurses' time spent delivering each of the school health activities as well as the frequency of each activity is captured in the model. The inputs obtained from the MOH are adopted in the model, which provides the baseline value for the school health nursing time simulation. The inputs for the baseline are shown in Table II. The output from the school health model is the total nurse time for the school health service. Fig. 7a illustrates the baseline simulation result in terms of total hours while Fig. 7b illustrates the baseline simulation result in terms of FTE nurses. The baseline simulation result of the nurse time required for delivering school health services is about 1080000 hours in year 2030, which is equivalent to 680 FTE nurses. It can be seen that the trend of the total nurse time is decreasing from year 2010 toward 2018 for both figures. This is because the total population numbers for the selected age groups in this study were decreasing, based on the Malaysian statistical department [25]. The total number of the population for this study is predicted to be increasing gradually, based on the same statistics, and thus the trend for the baseline simulation result is increasing too. Fig. 8 illustrates the total nurse time when applying the what-if analysis. There are a total of seven different sets of values representing total nurse time in hours from year 2008 until 2030. The first value only represents the total nurse time from year 2008 until 2030 for the baseline simulation model. The second and third values represent the projected total nurse time required based on the scenario of the population increasing by 10% and the projected total nurse time required based on the scenario of the population increasing by 30%, respectively.

It must be noted that these two scenarios are assumed to happen starting from year 2018 and onward; therefore, it can be seen that both projected values start to rise at year 2018. The total nurse time will be increased by about 10.19% and 29.63% for increments in population by 10% and 30%, respectively, in 2030 compared to the projected baseline value (baseline simulation result). The fourth value represents the projected total nurse time required based on the scenario of the population decreasing by 10%. This scenario will result in reducing the total nurse time by 10.19% in 2030 compared to the projected baseline value (baseline simulation result).

Table- II The input data for the baseline simulation

Models	Variables	Values
Basic health education	% Basic health education done by nurses	100%
	Time for basic health education program per student	1 minute per student (20 minutes per session for a group of 20 students)
Physical Examination	% Pre-school physical examination done by nurses	97.45%
	Nurse time for pre-school physical examination	15 minutes
	% Year 1 physical examination done by nurses	88.76%
	Nurse time for physical examination year 1	20 minutes
	% Year 6 physical examination done by nurses	88.21%
	Nurse time for physical examination year 6	15 minutes
	% Form 1 physical examination done by nurses	100%
	Nurse time for form 1 examination	20 minutes
	% Form 3 physical examination done by nurses	90.35%
	Nurse time for form 3 examination	10 minutes
Visual Examination	Time for visual examination	5 minutes
	% Visual assessment by nurses (year 1)	10%
	Time for visual examination year 6	5 minutes
	% Visual assessment by nurses (year 6)	10%
Immunization Program	% Year 1 require immunization done by nurses	100%
	Time for immunization year 1	15 minutes
	% Form 1 require immunization done by nurses	100%
	Time for immunization female form 1	10 minutes for each visit (2 visits)
	% Form 3 require immunization done by nurses	100%
	Time for immunization form 3	10 minutes
Referral letter writing	% Pre-school need referral	5.79%
	% Year 1 need referral	9.31%
	% Year 6 need referral	9.3%
	% Form 3 need referral	9.31%
	Time needed to write a referral letter	10 minutes

The last three values represent the projected total nurse time based on the scenario of zero nurse hours for basic health education, the projected total nurse time based on the scenario of zero nurse hours for basic health education together with a 30% reduction in physical examination duration, and, finally, the projected total nurse time based on the scenario of zero hours for basic health education together with a 30% reduction in physical examination duration for a population increase of 30%. These last three scenarios are assumed to be enforced starting from year 2018 and onward; therefore, it can be seen that the projected values start to drop at year 2018. Removing the task of delivering basic health education alone will result in reducing total projected nurse time by 4.6% in 2030 compared to the projected total nurse time based on the baseline simulation result. Removing the task of delivering basic health education as well as reducing the nurse time spent on physical examination by 30% will result in reducing the total projected nurse time by 24.6% in 2030 compared to the projected total nurse time based on the baseline simulation result. Finally, applying the scenario of removing the task of delivering basic health education as well as reducing the nurse time spent carrying out the physical examination by 30% on the 30% increased population will result in reducing projected total nurse time by 24.3% compared to the third value from the 30% increased population. Surprisingly, the projected nurse time from this last scenario is still less than the baseline simulation result by 1.5% in 2030, although the population total is assumed to be

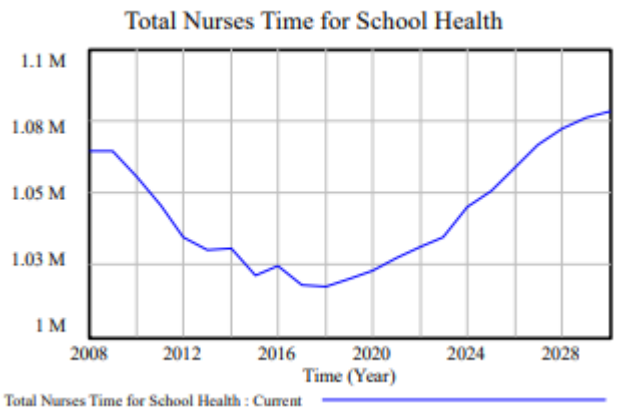

Fig. 7a Baseline simulation result for total nurse time (in hours)

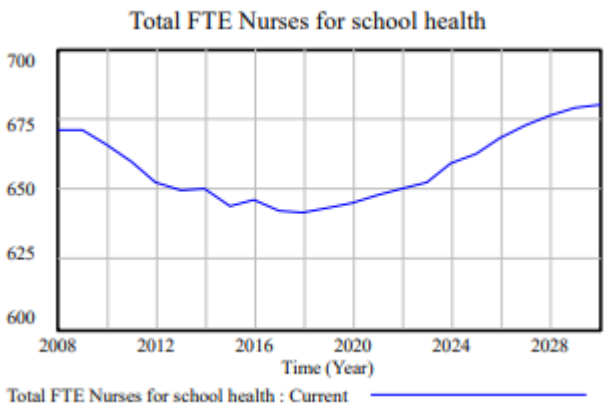

Fig. 7b Baseline simulation result for total FTE nurses for school health (head count)

far higher than the baseline simulation.

This study shows that an increasing population will lead to an increase in total nurse time required for school health and a decreasing population will lead to a decrease in total nurse time required. However, removing the task of delivering basic health education to the pupils as well as decreasing the time spent on physical examination will result in reducing the projected total nurse time required for the school health service. Therefore, it is recommended that policy makers should consider incorporating emerging technologies appropriately which can help in delivering basic health education as well as reducing the nurses' time spent on physical examination.

One possible solution to decrease workload and accomplish a better performance is by exploiting robotic assistance and virtual reality technology [26]. There is one pilot study that showed robot is able to assist in improving health literacy among children [27]. This indicates the potential of integrating robotic assistance in delivering school health services. However, there are challenges associated with this technology such as the lack of emotion in robots which is one of the major concern among the healthcare providers [28]. Thus, strategic planning and policy need to be formulated in order to find the balance between maximizing the full potential of emerging technology while ensuring the human element is not eliminated. Nevertheless, it must be noted that the utilization of emerging technology is only to supplement, not eliminate the nurses in delivering school health service

IV. CONCLUSION

This paper describes the innovation of using system dynamics approach for modeling and forecasting the specific total nurse time for school health service. The model can be used to determine the total nurse time for delivering school health service as well as to forecast the required total nurse time in the future. This is significant as time is often regarded as cost as well as a very significant resource. The proposed approach governs the relationships between various components of nurse time for the school health services. The components in the model are used to describe all the activities delivered by the nurses for the following services: basic health education, physical examination, visual assessment, immunization, and referral writing.

This is a particularly useful piece of research for health policy makers who are related to the nursing profession. The developed model was then run as a form of computer simulation by incorporating various scenarios for further investigation in order to assist the decision-making process.

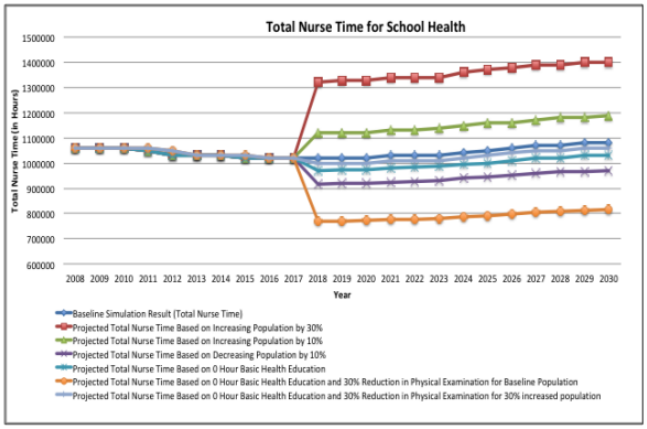

Fig. 8 Total nurse time when applying what-if analysis

Among the what-if scenarios considered is what happens if the student population remains as projected by the statistical department? What happens if it increases? What happens if it decreases? What should be done in order to reduce the total nurse time in order to ensure nurses can provide sufficient coverage for the school health service?

Based on the school health model, it can be seen that removing the basic health education portion from the nurse task as well as reducing the physical examination duration will reduce the total projected nurse time for school health. Hence, it is recommended that policy makers should consider incorporating appropriate emerging technologies that can help in reducing the nurse service time. The adoption of the emerging technologies is not a complete replacement for the nursing profession; rather, it can be seen as a collaborative effort for achieving better healthcare services. As a conclusion, the solution could be use to assist in planning and formulating a new policy for the nurse healthcare workforce, which could be considered by the Ministry of Health in Malaysia.

APPENDIX

Table- III List of selected variables and its equations in the Vensim simulation model

Variable Name	Equation
Number of pre-school students	Population Age 5 & 6 x % Population Age 5 & 6 in Pre-School
Number of Year 1 Primary School	Population Age 7 x % Age 7 in Primary School
Number of year 6 Primary School	Population Age 12 x % Population Age 12 In Year 6 Primary School"
Number of Form 1 Female Secondary School	Female Population Age 13 x % Female age 13 In Form 1 Secondary School"
Number of Form 3 Secondary School	Population Age 15 x % Age 15 In Form 3 Secondary School
Total students for basic health education	Number of pre-school students + Number of Year 1 Primary School + Number of Year 6 Primary School + Number of Form 1 Female Secondary School + Number of Form 3 Secondary School
Total Nurse Time for Basic Health Education	Time for Basic Health Education Program per Student x Total students for basic health education x % Basic Health Education done by nurses
Total Nurse Time for PRE-School Physical Examination	Nurse Time for PRE-School Physical Examination x Number of Pre-School Children Who Require Examination x % Pre-School Physical Examination Done By Nurses"
Total Nurse Time for Physical Examination Year 1	Number of Year 1 Who Require Examination x % Year 1 Physical Examination Done By Nurses x Nurse Time for Physical Examination Year 1
Total Nurse Time for Physical Examination Year 6	Nurse Time for Physical Examination Year 6 x Number of Year 6 Who Require Examination x % Year 6 Physical Examination Done By Nurses
Total Nurse Time for Physical Examination Form 1	Number of Female Form 1 Student Who Require Examination x Nurse Time for Form 1 Examination x % Form 1 Physical Examination Done By Nurses
Total Nurse Time for Physical Examination Form 3	Number of Form 3 Student Who Require Examination x Nurse Time for Form 3 Examination x % Form 3 Physical Examination Done By Nurses
Total Nurse Time for Physical Examination	Total Nurse Time for PRE-School Physical Examination + Total Nurse Time for Physical Examination Year 1 + Total Nurse Time for Physical Examination Year 6 + Total Nurse Time for Physical Examination Form 1 + Total Nurse Time for Physical Examination Form 3
Total time for Visual Assessment by nurses for year 1	Number of Year 1 Who Require Examination x Time for Visual Examination x % Visual Assessment by Nurses (Year 1)
Total time for Visual Assessment by nurses for year 6	% Visual Assessment by Nurses (Year 6) x Number of Year 6 Who Require Examination x Time for Visual Examination year 6
Total Nurse Time for Visual Examination	Total time for Visual Assessment by nurses for year 1 + Total time for Visual Assessment by nurses for year 6
Total Time Required for Student Year 1 Immunization	Number of Year 1 Who Require Examination x Time for Immunization Year 1 x % Year 1 Require Immunization Done by Nurses
Total Time Required for Student Female Form 1 Immunization	Number of Female Form 1 Student Who Require Examination x Time for Immunization Female Form 1 x % Form 1 Require Immunization Done by Nurses
Total Time Required for Student Form 3 Immunization	Number of Form 3 Student Who Require Examination x % Form 3 Require Immunization Done by Nurses x Time for Immunization Form 3
Total Nurse Time for Immunization	Total Time Required for Student Year 1 Immunization + Total Time Required for Student Female Form 1 Immunization + Total Time Required for Student Form 3 Immunization
Number of Pre-school Require Referral	Number of PRE-School Children Who Require Examination x % Pre-School Need Referral
Number of Year 1 Require Referral	Number of Year 1 Who Require Examination x % Year 1 Need Referral
Number of Year 6 Require Referral	Number of Year 6 Who Require Examination x % Year 6 Need Referral
Number of Form 3 Require Referral	Number of Form 3 Student Who Require Examination x % Form 3 Need Referral
Total Nurse Time to Write a Referral Letter	(Number of Pre-school Require Referral + Number of Year 1 Require Referral + Number of Year 6 Require Referral + Number of Form 3 Require Referral) x Time Needed to Write a Referral Letter

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