Synergizing Generative AI in System Dynamics Modelling and Simulation – An Exploration with Application in Health Human Resource Projection

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.91200040

Received: 12 December 2025; Accepted: 20 December 2025; Published: 31 December 2025

ABSTRACT

Generative AI tools, such as ChatGPT, Copilot, Gemini AI, and Claude 3, have become a trend or a must-have tool in daily operations in most organizations across various domains. This includes the rapid usage of Generative AI tools in the research domain and activities. Among the established and powerful research approaches that can understand complex systems is System Dynamics modelling and simulation. This paper aims to explore the potential of synergizing generative AI in System Dynamics and modelling simulation. The application of ChatGPT as the chosen Generative AI tool is discussed from two different categories of utilization. The first category is used solely for code generation, while the second category is utilized based on the stages in System Dynamics. Nurse supply projections, developed using System Dynamics modelling and simulation, serve as an example for exploration. Although this advanced technology can accelerate the modelling process, human intelligence is still required to validate the generated responses. In fact, this paper highlights the empowerment of human intelligence in critical thinking through the integration of generative AI tools, such as ChatGPT, in facilitating the research process.

Keywords: System Dynamics, Generative AI, ChatGPT, Health human resource projection, Nurse Projection.

INTRODUCTION

System dynamics is a computer-aided approach to modelling a system to analyse and understand its dynamic behaviour over time, using stocks and flows. It can represent complex scenarios or systems for effective projection across various case studies by integrating all interactions among the system's elements. The construction of the model involves a 'stock and flows diagram', which is useful for studying changes in the system over time. All variables and parameters, along with their time-varying values, are captured in the model. System dynamics is a powerful approach for testing policies or strategies before the implementation phase in a real environment. Hence, decision-makers can explore all the potential impacts and determine the most effective decision or approach by simulating various scenarios using the system dynamics modelling and simulation. As a matter of fact, system dynamics' capability to analyse nonlinear and complex systems has been proven and impactful across applications such as healthcare Darabi and Hosseinichimeh, N. (2020),

agriculture Wang, W., Li et. al. (2022), cybersecurity Khalid , Shiwakoti and Stasinopoulos (2022), urban planning Bottero, Datola and De Angelis (2020), and many more.

Approximately in 2010, the rise of big data, driven by advanced computing capabilities, awakened most of the knowledge domain to the significance of this technology. It cannot be denied that big data has a significant impact on system dynamics modelling and simulation. One effect is that model accuracy is enhanced by the availability of a large number of relevant datasets (Yang, Li, and Zhou, 2019). Rather than relying on assumptions for certain scenarios or conditions, modelers can obtain exact values from available data that reflect the contexts. Real-time data analysis can be facilitated with the availability of real-time data. It will allow the real pattern or trend over time to be embedded in the system dynamics model (Pathak et. al. 2018). Moreover, big data analytics enables the discovery of hidden patterns in complex systems, thereby supporting robust scenario planning. It must be noted that robust scenario planning is essential in the modelling stage, as it can assist decision-makers or stakeholders in effective decision-making.

Moving on, Generative AI raised a storm of surprise, ethical concern, and excitement across different societies worldwide and various industries. Generative AI is a part of Artificial Intelligence technologies that can create content such as text, images, and videos. It is a recent breakthrough in AI that changes the way content creation is approached. This technological advancement raised many questions, such as "Will this new advanced technology disrupt the existing traditional industries, skills, and jobs, or perhaps only bring benefits to the economically privileged ones?" Despite this criticism, the adoption of Generative AI has spread widely across domains such as retail, business, education, healthcare, and many others (Fui-Hoon et. al. ,2023).

In scientific research, Generative AI is an undeniable tool for accelerating innovation. In other words, it is an assistance tool that improves and facilitates the research process. According to (Akhavan and Jalali, 2024), there is still a lack of guidelines for deploying Generative AI, such as ChatGPT, in simulation research. While it is believed that Generative AI is a valuable tool in the research process, how to use it, especially in scientific simulation research, needs to be explored. Besides, while trying to avoid undermining human intelligence, another question to focus on is: "How to not diminish critical thinking while still integrating the Generative AI in the research process?"

This paper aims to explore how to synergize Generative AI in system dynamics modelling and simulation research. The case study used in this paper is based on a health human resource projection using a system dynamics approach. Two main contributions are highlighted in this paper and are intended for all academics, researchers, and simulation practitioners. The first contribution is to provide additional guidelines for the use of Generative AI in system dynamics modelling and simulation. The use of this advanced tool is illustrated in two categories: full code generation and stage-by-stage use. The second contribution is the practical application of ChatGPT, demonstrated through a case study on health human resource projections. It must be noted that this paper is one of the initiatives to experiment with the capabilities of Generative AI in the context of system dynamics modelling and simulation, in line with the evolving trend of AI in these areas.

Related Works

Generative AI

Generative AI is a subset of Artificial Intelligence technologies that uses supervised and unsupervised machine learning, as well as deep learning, to generate content. This remarkable type of AI is mainly derived from generative modelling, which, through a joint probability distribution, enables the production of new synthetic samples (Feuerriegel et. al., 2024). Generative AI models learn from vast amounts of data to generate content that resembles the training data. The rapid advancement of Generative AI resulted from several factors: advances in computational power, the availability of large datasets for model training, advances in deep learning, transfer learning and pretraining, neural networks with modern architectures, and finally collaboration among communities and open-source initiatives (Hagos, Battle and Rawat ,2024). Some generative AI tools are ChatGPT, Gemini, Copilot, DALL-E, and many more.

Among the popular Generative AI tools used in research is ChatGPT, which is known for its versatility. According to (Rahman and Watanobe ,2023), the use of ChatGPT in research allows researchers to focus more on experimentation and implementation, as this tool can facilitate the research writing process. Interestingly, a step-by-step guide on the proper use of ChatGPT for research is provided, emphasizing the main eight components: title and title page, abstract and summary, introduction, literature review, methodologies, data and results, discussion and conclusion, and, finally, references (Biswas, 2023). Furthermore, the researcher can also benefit from ChatGPT in exploring unexplored research ideas (Rahman and Watanobe ,2023, Rahman et. al, 2023).

The widespread use of generative AI, such as ChatGPT, in research is inevitable and will continue to proliferate across various domains. It includes the use of ChatGPT in healthcare education, research, and practice. An interesting review by (Sallam, 2023) has listed four main benefits of ChatGPT in healthcare related domain which are: (1) scientific writing improvement as well as research equity and versatility enhancement; (2) healthcare research efficiency in terms of data analysis, generation of code, reviewing literature, time efficiency in experimental design, discovery and development of drug; (3) advantages for the delivery of healthcare (such as increased health literacy, cost savings, documentation, tailored medicine, and workflow efficiency); and finally (4) advantages in health care education, including improved individualized learning and the focus on both problem-based learning and critical thinking. Furthermore, the review highlights the urgent need for attention and engagement from all stakeholders to develop appropriate guidelines and regulations to ensure the safe and responsible use of ChatGPT capabilities.

The use of generative AI in research related to modelling and simulation is also demonstrated by [8] for verbal translation and written commands to achieve desired results, thereby assisting the research process. It is significant for users to formulate prompts that produce meaningful responses from generative AI tools. The work uses a simplified COVID-19 onset and its economic impact (GDP) in the United States to illustrate the application of generative AI in simulation modelling. The authors emphasize that generative AI could never replace human thinking. However, it is a valuable tool that facilitates researchers in the research process by reviewing existing content from other researchers and enhancing the implementation of ideas in simulation modelling. Another interesting work examined the use of ChatGPT to prompt the generation of modelling code for changes in transportation mode among elementary school students due to the COVID-19 pandemic. The work demonstrates that ChatGPT could not produce a concise or executable model, indicating the current state of the technology in modelling and simulation (Frydenlund et. al, 2024)

System Dynamics Modelling and Simulation

System Dynamics is one of the key approaches in simulation modelling, alongside Discrete Event Simulation and Agent-Based Simulation (Wofuru-Nyenke , Briggs and Aikhuele, 2023). It is used to analyse and represent complex systems involving multiple actors and interactions (Dellas et. al., 2022), providing insights into how a system's structure shapes its behaviour and outcomes (Şenaras, 2018). Typically, System Dynamics is applied to large-scale or macroscopic simulations, helping researchers explore the dynamic patterns and long-term consequences of system behaviour (Khosravi, Haghshenas and Salehi 2020).

In the field of health human resources planning, system dynamics modelling and simulation have become an essential approach for addressing potential workforce shortages or surpluses (Davahli, Karwowski and Taiar, 2020). This approach can represent the complex interactions among various factors influencing the supply and demand of human health resources, such as education, workforce attrition, and national healthcare needs. Several studies have used the system dynamics approach for nurse projection, since nurses are among the professions critical to health human resources (Caulfield, Hynes and O'Connor, 2022, Abas et al., 2018). System dynamics has remained a preferred choice for health human resource projections; hence, this study extends the current context of nurse projection by exploring it using Generative AI.

Synergizing Generative Ai In System Dynamics Modelling And Simulation

In this work, ChatGPT is chosen as the Generative AI tool for exploring complementarities between Generative AI and system dynamics modelling and simulation. It is selected because it is known as a versatile

AI tool and works well with a wide range of applications. In general, there are two approaches to using ChatGPT to develop a simulation model, as illustrated in Figure 1. From the figure, the first approach is to use ChatGPT's code fully, whereas the second approach is to use ChatGPT at the stages of system dynamics modelling and simulation.

The first approach to fully using it must be associated with the prompt engineering concept, detailing three components: role, task, and format. Specifying a role by explaining who we are or what role you want ChatGPT to play will set the context for the response. Specifying the task will set the objective or aim of the response, while selecting the format will set the desired structure or format of the generated response.

In the case study of nurse supply projection, we use the following prompt for the first approach: "You are the data scientist working in the department of health planning in ministry of health. You need to develop a nurse supply projection model based using system dynamics following the needs-based approach. Write the code in Vensim simulation software."

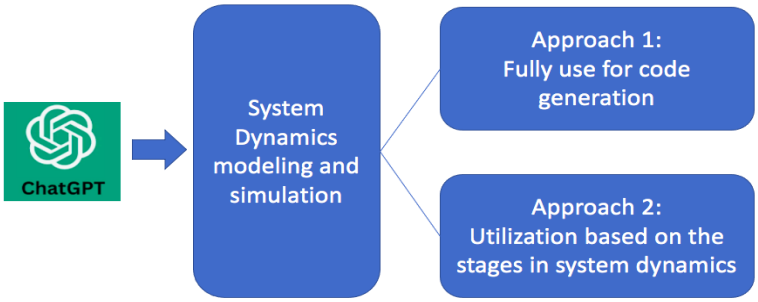

Figure 1. The approach of using ChatGPT for System Dynamics modelling and simulation

In the above prompt, the three basic components of the prompt are as follows:

1. The role: You are a data scientist working in the department of health planning in the Ministry of Health.

2. The task: Develop a nurse supply projection model using system dynamics, following a needs-based approach.

3. The format: Write the code in Vensim simulation software

The second approach to using ChatGPT for system dynamics modelling and simulation is to use it in stages, as illustrated in Figure 2. From the figure, it is necessary first to identify the stages of the system dynamics modelling and simulation process. In this paper, the stages of the system dynamics modelling and simulation process include problem articulation, dynamic hypothesis, simulation model development, testing and validation, and, finally, policy and evaluation formulation (Sterman et. al., 2015).

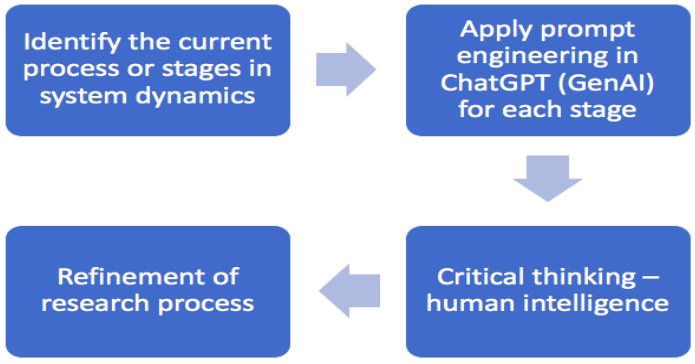

Figure 2. Utilization of ChatGPT based on the stages in system dynamics

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XII December 2025

To integrate ChatGPT in this approach, prompt engineering is applied at each stage of the process. Each prompt must cover the three components described previously: the role, task, and format. The prompts used at every stage of the nurse supply projection case study are presented in Table 1. From Table 1, ChatGPT is embedded at each stage through a crafted prompt that covers role, task, and format. The prompt is crafted so that the response covers the targeted deliverables at each stage of the system dynamics process. For example, the output from the first stage is problem articulation; hence, the work' problem articulation' is highlighted in the prompt.

The responses generated from the ChatGPT prompt for each stage need to be evaluated for their relevance and appropriateness to the research. In this case, human intelligence is required and cannot be replaced by ChatGPT; critical thinking, assessing appropriateness, and improving response output still require human intervention. The human must remain the subject-matter expert for the respective field. Finally, the response from ChatGPT, which has been "massaged," will serve as input for refining the research process, including model development.

Table 1. The set of prompts that was used in every stage for the case study of nurse supply projection

The stages in System Dynamics modelling	The prompt in ChatGPT
Problem articulation	You are the director of the planning department in the Ministry of Health. You need to figure out the total number of nurses required and supplies for national healthcare planning (for the next 10 years), for which you have formed a small team to conduct the research. Please provide the **problem articulation** (covering the current context) for nurse supply projection using system dynamics modelling and simulation, following the Needs-based approach.
Dynamic hypothesis	You are a researcher on the team for the nurse supply projection project (for the next 10 years) using system dynamics modelling and simulation. You need to formulate a **dynamic hypothesis** for the nurse supply projection using the system dynamics modelling and simulation. Please provide the relevant dynamic hypothesis following the Needs-based approach.
Simulation model development	You are a researcher on the team for the nurse supply projection project (for the next 10 years) using system dynamics modelling and simulation. You need to **develop a nurse supply projection model** based on system dynamics using a Needs-Based approach. Please provide the model in the Vensim simulation environment.
Testing and validation	You are a researcher on the team for the nurse supply projection project (for the next 10 years) using system dynamics modelling and simulation. You need to **ensure the developed model is appropriate** for nurse supply projection following the Needs-based approach. Please provide a series of tests to assess the model's confidence.
Policy and evaluation formulation	You are the head of the research team for the nurse supply projection project (for the next 10 years) using system dynamics modelling and simulation. You need to finish up the project by **evaluating various possible scenarios for nurse planning** nationwide. Please provide all scenarios and strategies to close the gap between the supply and demand.

RESULTS AND DISCUSSION

The result from the first approach in this exploration is the Vensim code generated by ChatGPT. Each component, such as constants and parameters, stocks and flows, initial conditions, and model settings, is

explained in the responses. The result that needs to be analysed is also provided in the responses. In this case study, the responses suggest analysing nurse supply and demand and the nurse shortage. Apart from that, the reactions also suggest some features to make the model more comprehensive. In this case study, the responses offer suggestions, including different scenarios for nurse education intake, policy interventions, and cost analyses, to enhance the model. The researcher could copy and paste the code directly into the text editor in Vensim software if the researcher is familiar with text coding. On the other hand, if the researcher is not familiar with the text editor, they could build the model as a sketch by following the generated code. In this case study, the generated Vensim text code is as follows:

```
\* Nurse Supply Projection Model *\

\* Time settings *\

SIMULATION TIME FINAL = 50

TIME STEP = 1

INITIAL TIME = 0

\* Constants and parameters *\

PopulationInitial = 1000000 \| Initial population

AnnualPopulationGrowthRate = 0.01\| Population growth rate per year

NurseToPopulationRatio = 0.005 \| Desired ratio of nurses to population

NurseAttritionRate = 0.05 \| Annual attrition rate of nurses

NurseEducationRate = 0.002  \| Base rate of new nurses graduating per year (fraction of population)

\* Stocks and flows *\

NurseSupply = INTEG(NewNurses - NurseAttrition, InitialNurseSupply)

NewNurses = NurseEducationRate * Population

NurseAttrition = NurseAttritionRate * NurseSupply

NurseDemand = Population * NurseToPopulationRatio

\* Initial conditions *\

InitialNurseSupply = 3000

\* Dynamics of population *\

Population = INTEG(PopulationGrowth, PopulationInitial)

PopulationGrowth = AnnualPopulationGrowthRate * Population

\* Output equations for analysis *\

NurseShortageOrSurplus = NurseSupply - NurseDemand

\* Model settings *\
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SIMULATION TIME START = INITIAL TIME

In this case study, the text code is manually transformed into a Vensim sketch, as illustrated in Figure 3. In Figure 3, the simulation result graph is embedded manually to facilitate monitoring. The graph is chosen based on ChatGPT's suggested result analysis. In this case study, the value of the parameters and constants remained as indicated by ChatGPT.

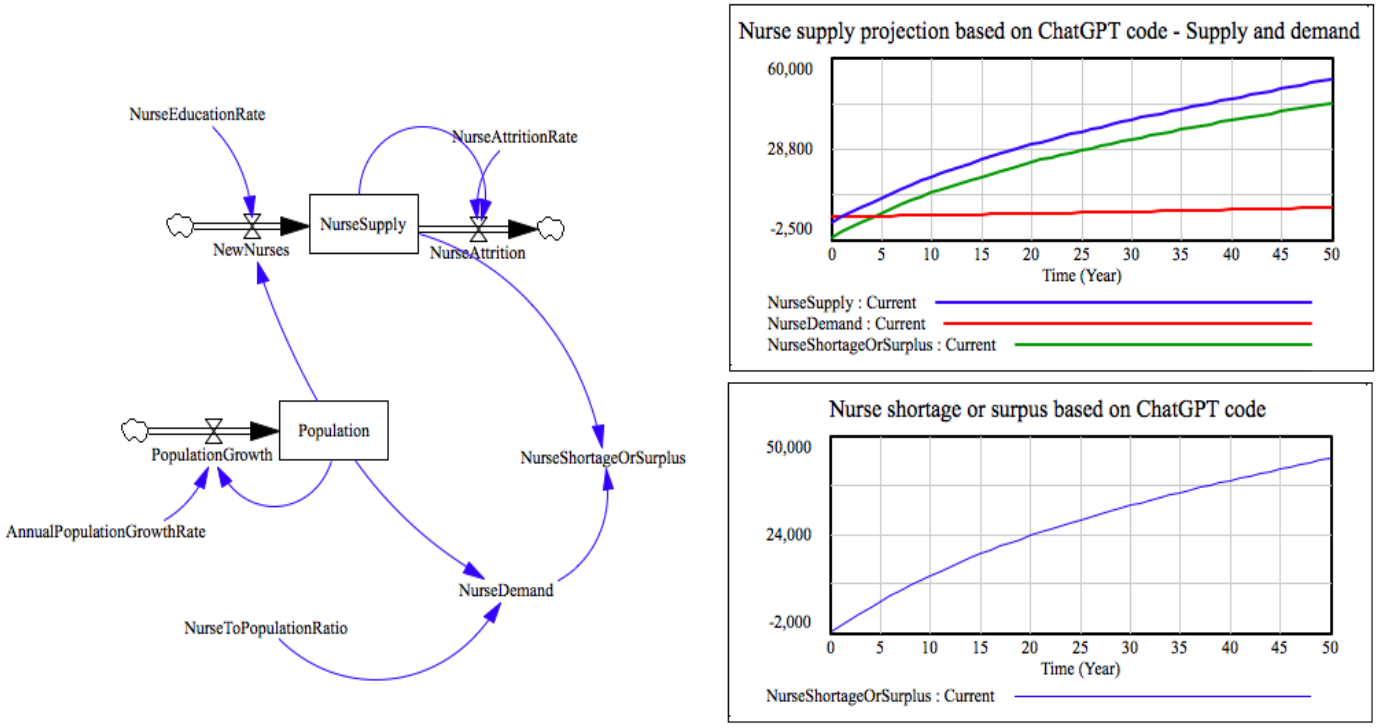

Figure 3. The sketch was obtained manually based on the Vensim text code generated by ChatGPT

Based on Figure 3, the text generated by ChatGPT follows a basic structure for nurse supply projection. Compared to the existing model developed in Nurse supply Malaysia [22], this initial model (as shown in Figure 3) is insufficient to capture the level of complexity covered by the existing work. For example, the existing work includes sub-models to represent nurse supply by year of enrolment and to define the age group of the nurse population. In addition, the existing work consists of a sub-model that represents the full-time equivalent (FTE) of nurses available nationwide.

In this paper, the second approach is preferred for system dynamics modelling and simulation research. The prompt needs to be crafted following the concept of prompt engineering for each stage. It must be noted that the result from the prompt in ChatGPT may exceed what is asked, so it should be filtered to only what is necessary and appropriate. The full results of the prompt from this case study are not shown in this paper because they are too long. However, the relevant information that can be derived from the ChatGPT responses for each stage is summarized in Table 2. From Table 2, ChatGPT has significant potential to facilitate the system dynamics modelling and simulation process.

Table 2. Key points generated by ChatGPT based on the stages in System Dynamics modelling and simulation

The stages in System Dynamics modelling	Generative AI responses
Problem articulation	Context Problem formulation Objectives

Dynamic hypothesis	Key variables and components Dynamics hypothesis Structure of Causal Loop Diagram
Simulation model development	Model components (Stock, Flows, Auxiliary variables) Vensim Code (as text) & explanation
Testing and validation	Structural validation Behavioural validation Extreme condition test Policy and intervention testing Parameter calibration and validation Stakeholder review and expert validation Performance testing
Policy and evaluation formulation	Scenarios and possible outcomes Strategies

The ethical and limitations of using Generative AI in System Dynamics modelling and simulation for health human resource projection are also crucial aspects to be discussed. It cannot be denied that bias is an issue, as Generative AI models are trained on historical data. Inaccurate projections and unfair policy recommendations could result from these biases, potentially impacting the recruitment, training, and deployment of health human resources. Besides that, data privacy and confidentiality are among the main concerns when using this technology. Large volumes of data, such as workforce distribution, employment patterns, and patient care requirements, are needed to train AI models. Privacy issues arise from the use of private health and work data, particularly when anonymization is insufficient. Moreover, data limitations, including outdated, incomplete, or biased health human resource data, will lead to unreliable projections. Hence, it is recommended that healthcare professionals and policymakers be involved in model validation and decision-making. It is also advisable to compare those AI-generated projection models with real-world workforce trends and expert forecasts.

CONCLUSIONS

This paper proposes an approach to using Generative AI in system dynamics modelling and simulation. Based on the exploration, there are two approaches: use for code generation only or use based on the stages of system dynamics. Generative AI could provide an initial idea for initiating the modelling process, from articulating the current problem context to the last stage in system dynamics modelling: policy and evaluation formulation. It is achieved through responses generated by a prompt crafted in generative AI. However, one must note that it cannot automatically develop the model as in a Vensim file; the most it can do now is provide the Vensim code in a text file. Hence, human intelligence to develop the model in the simulation software is still required.

Furthermore, the complexity of the model that represents reality's uniqueness, or the level of depth in certain applications, such as human resource projection, could differ from what generative AI provides. Therefore, fine-tuning the code generation provided by Generative AI is necessary to align with the researcher's

expectations. Nevertheless, responses from Generative AI may offer other criteria we might overlook, so this advanced technological tool is great to use hand in hand.

As a matter of fact, although Generative AI has stormed the world, human intelligence is still required to broaden perspectives and determine what to investigate whenever possible. The purpose of this paper is not to hinder the use of Generative AI, but rather to encourage its use alongside human intelligence. For instance, it is not wise to rely solely on Generative AI, as we need to validate the generated response or output. If this advanced technology is used wisely, human intelligence, especially in critical thinking skills, will not be diminished. Furthermore, it would be great if other researchers from diverse bodies of knowledge explore and propose frameworks for using Generative AI scientifically and wisely in their respective areas.

Conflicts Of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

ACKNOWLEDGMENT

The authors would like to thank the Faculty of Artificial Intelligence and Cyber Security (FAIX), the OptiMAS research group, and the Centre for Research and Innovation Management (CRIM) of Universiti Teknikal Malaysia Melaka (UTeM) for their assistance and support in funding this research.

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