Topics in Middle Eastern and African Economies
Proceedings of Middle East Economic Association
Vol. 23, Issue No. 1, May 2021

ARE MODELING METHODS IN HEALTH ECONOMICS CHANGING?[1]

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Abstract

Health is a complex system since the appearance of illness and sickness has high uncertainty. In this regard, health economics is a complex system that the emergence of health care demand is uncertain. Thus, evaluation of health economics using classical mathematical methods produce insufficient and incorrect outcomes. Therefore, in this work, complex system tools and methods assessing the health economics and the health care market were investigated to illustrate the superiority of the simulation methods. In recent years, researchers tend to use simulation and modelling based applications to assess the health care market instead of classical methods such as cost-effectiveness and cost-utility. Hence, methods like discrete event simulation, system dynamic modelling, and agent-based modelling attract the attention of researchers. Such methods were used in the evaluation of different health care policies and the assessment of the simulation outputs. Moreover, simulation methods were also used in the minimization of health care expenditures and the assessment of health insurance repayment. It was concluded that researchers tend to use simulation methods to evaluate health economics rather than classical approaches.

Key words: Computational economics, Simulation modelling, Health economics

JEL Classification: C61, C63, I11

1. Introduction

Systems that are interdependent and self-organizing, evolving, nonlinear and path-dependent are called complex adaptive systems (Holland and Miller 1991). The relationship and processes

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[1] This work is produced from PhD thesis research of Demet Topal Koç which is entitled "Health Economics: Prediction of Healthcare Supply and Demand Using Agent-based Modelling and Machine Learning" supervised by Prof. Dr. Ercan Eren.

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between heterogeneous agents and the health system create a complex adaptive system (Kitson et al. 2018). This situation causes inadequacy of classical methods in predicting behaviours in the health system and in system management. Classical methods used in health services and market analysis deal with specific situations under some assumptions. However, tools used in the analysis of complex systems are needed to understand the overall system and to provide more effective solutions. Health systems consist of many national and international institutions, such as local institutions such as family medicine, as well as regional or national comprehensive hospitals. Therefore, it can be said that cost-effectiveness, cost-benefit, and cost-utility analysis, which are traditional analysis tools of health economics, are not sufficient for performance evaluation, development of effective policies, and optimizations.

In this study, in this context, computational modelling methods, which have become widespread with the recent developments in informatics and computer technologies within the scope of health economics, will be discussed. Among these methods, the most frequently used agent-based modelling, system dynamics, and hybrid models will be briefly explained and the literature using these methods will be examined.

2. Health Economics and Complexity

Health economics examines the amount, organization, financing, effectiveness, efficiency, and the impact of individual or national protective, curative, and rehabilitative health services. All activities carried out for the protection and recovery of health are called health services (Phelps 2018). There are two important aspects of health in terms of economy. First, a healthy society can work more and more effectively and thus contribute to the economy. Secondly, as a result of the deterioration in health status, the disease has economic damages both to the individual and to the society (Ersöz 2008)

Access to healthcare is considered as a fundamental human right and therefore there is public intervention in this issue. Efforts are made to pay health insurance and to provide healthcare services to people in every region by the public. Because when the sick individual cannot receive treatment, not only that individual is affected, but also social costs arise for those around him. In this context, health economics uses the methods and tools of economics to ensure efficient and fair use of resources in the healthcare market. Thus, an answer is sought to the question of what should be done to improve health outcomes such as health development, mortality and morbidity, as well as to address health inequalities.

Due to the developing technology and correspondingly increasing health expenditures, interest in the economic evaluation of health services has increased. Generally, cost benefit analysis and similar evaluations are made in order to ensure efficiency in healthcare services. However, it was not possible to add the high uncertainty and complex structure in health services to these economic evaluation methods. Because, in cost analysis, it is not possible to evaluate the mutually dependent structure of the units in the health system and the effects of many factors at the same time. Traditional methods in health economics use Newtonian mathematics. Here it is assumed that activities and performance can be accurately defined, the units are rational, and the techniques used with a reductionist approach are fixed. The human body is perfect and diseases to be defects. Health care problems are divided into small parts and it is accepted that these parts, which are isolated for each problem, describe the problem in the most appropriate and complete way (Lessard 2007). Although there are deficiencies in the reductionist approach and perfectly functioning machine approach, nonlinearity and reflecting the interdependence of the units, they are used in policy and decision-making processes in health care. On the other hand, with the rapidly developing computer technologies in recent years, agent-based modelling as applications of complexity theory is used in modelling the economy (Eren 2013). Complexity is used to explain social systems and changes and interactions.

Key features of complex adaptive systems: (Plsek 2001)

Adaptable units: The units in the system can change themselves. For example, people can learn.

Simple rules: Simple rules applied locally can generate complex outputs.

Nonlinearity: Small changes can have huge effects. For example, while health education campaigns may have little impact; a local rumour can affect the entire industry.

Unpredictability of details: It can be predicted, but it has limits. For example, predictions can be made about when and how a new virus outbreak will occur, but it is not possible to make predictions with great accuracy.

Natural order: Self-organization is characteristic of complex systems. The system has a layout without a central control. For example, the internet and markets are in order without a central control.

Context and nested system: Complex systems can be inside other systems and contain sub-systems. For example, hospitals are part of the national health system and hospitals also have a variety of clinics.

Co-evolution: Complex adaptive systems proceed in a constant tension and dynamic balance. Healthcare professionals can compete and work together at the same time. Paradox, uncertainty, and anxiety are part of the complex adaptive health system. However, new diagnosis and treatment methods are obtained through the joint work of many employees from different fields.

There are two types of complexity, complex physical systems, and complex adaptive systems. Studies on complex physical systems deal with geometric sequences of components in the system. The interaction in the sequences takes place with effects spread from the closest neighbours. In complex adaptive systems, more unstable components are handled. Here, the units in the system learn and adapt with their interactions with other intermediaries. These interactions take place with agents, and new agents may arise during adaptation. This increases the complexity. In complex adaptive systems, agents have three levels of activity. These are: performance, reliability allocation, and rule discovery. Performance specifies the types of behaviour of the agent and is determined by a conditional If / Then rule set. If x and y signals are in the list, then the signals determined and received by rules such as add w signal to the list are used when connecting the rules to form sequences and sub-programs, as in computer programming (Holland 2020). This is particularly useful when modelling agent based. Agents' behavioural rules are determined by various conditions, agents can receive rewards or punishments with certain behaviours (such as waiting longer in the emergency room) and change their next behaviour according to these results.

There is a diagram developed by Stacey, as shown in the figure, in order to better understand complex adaptive systems and to use appropriate analysis tools (Baghbanian and Torkfar 2012). He divided the systems into three groups according to the degree of uncertainty and joint decisions. These; plan and control areas, complexity, and chaos areas. The vertical axis shows agreement and the horizontal axis shows certainty (uncertainty). While the degree of precision is related to cause and effect information; choosing and making decisions about policies to be implemented is close to certainty when the cause and effect relationship is known. Background information is needed. In other words, as the precision decreases in the diagram, when the uncertainty increases; the cause and effect connection lose clarity, making predictions from experience difficult.

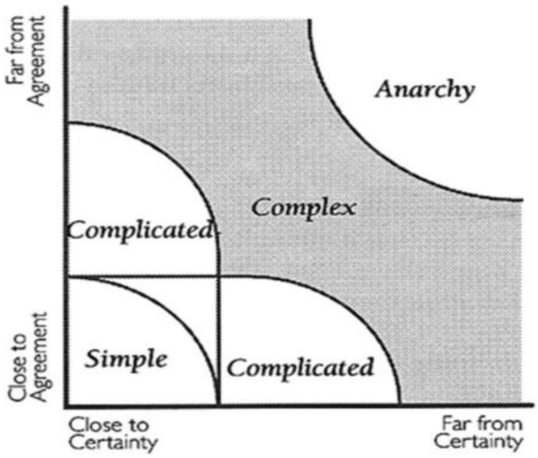

Figure 1: Stacey Diagram

(Baghbanian and Torkfar 2012)

Health economics generally works in a field that is close to agreement and certainty. In this area, models are explained using historical data and techniques that make future predictions are used. Stacey cited areas with high uncertainty and low agreement on desired outcome and areas where agreement but low cause and effect relationship, in other words, areas where precision is low, as complicated areas. Expertise and experience in these areas are important. In the diagram, the area where uncertainty increases, and agreements decrease is called chaos. Here, the reductionist approach and traditional methods cannot be used. In addition, the area between chaos and traditional approaches is named as complexity. Traditional methods are not sufficient in this area, too, instead, methods and analysis tools that include uncertainty, relationships between units and heterogeneous units are needed in the model. Agent-based modelling and system dynamics modelling can be used as complexity tools.

3. Computational Modelling

Computational modelling has been used frequently in the analysis of complex structures such as healthcare services in recent years. Agent-based modelling (ABM) and system dynamics (SD) models are methods that can analyses the mechanism in complex systems by modelling micro and macro-level behaviours. In this study, ABM and SDM methods and hybrid computational models, which can also be used in simulation and optimization, are discussed.

Agent-based modelling method can be used in dynamic patient flow or dynamic personnel activities optimization where methods such as differential equations and discrete event simulation are insufficient. Stochastic analysis can be done with ABM, which is non-deterministic and closer to the real world. As agents, patients can learn and infer from other patients, healthcare professionals, and their own experience in the healthcare system. In other words, adaptive behaviour can be modelled (Z. Liu et al. 2014). In addition, SD enables the system to be examined as a whole and at the same time reflects the feedback in the system and the change of the system over time.

System Dynamics Modelling

It examines the behaviour of the system at the macro level, the movement of resources or their quantitative change over time. The system is simulated by using differential equations with state variables and their changes over time (P. Liu and Wu 2016). The formal representation of the SDM method is the stock flow diagram.

Agent Based Modelling

Unlike SDM, the system can be represented not as a whole, but on a unit basis and in every aspect. The behaviour of the whole system can be modelled from the bottom-up (Wilensky and Rand 2015). Agents can learn from their experiences and make their own decisions according to the established rules. It can communicate with other agents and the environment. There are one-to-one, one-to-n and one-to-location communication types.

Hybrid Modelling

These are models in which two or more methods are used. Separate models have limitations, but these restrictions can be eliminated with hybrid models.

4. Literature

SDM and ABM methods are used to economically activate practices and policies in the field of health, from decision-making processes in health systems to optimization of patient waiting times. Before implementing high-cost policies and practices in the health system, trials can be made with simulations without risk and with much lower budgets, and their effects and results can be observed. Usually "what if" scenarios are used and we assume that these are tried to be optimized for applications that are being done or planned to be done (Atkinson et al. 2015).

4.1 Literature on System Dynamics Modelling

One of the areas where uncertainty in the health system is highest is the emergency services. Since it is not clear how and when the health service demand will occur, the health service supply must be ready. However, not all resources of the hospital can be used for emergency services to meet the demand. At this point, the health institution needs to plan in a way to use resources optimally and according to the region where it is located and the general demand trend. Lane (1998) modelled an emergency room in London in his study. System dynamics modelling has been carried out to determine the effective factors in optional surgeries and the factors that cause delays in the emergency department. As a result of modelling, it has been observed that if the number of beds is reduced, patient waiting times in the emergency department will increase and cancellations in optional surgery records will increase. In the study of the same author (2000) an emergency service in London was modelled and the relationship between patient waiting times and the number of beds in acute hospitals was examined. The number of beds was changed in the first scenario and permanent changes were made in the second scenario. It has been observed that the reduction in bed capacity not only increased patient waiting times, but also caused deterioration in other performance measures and inefficient use of resources.

One of the studies evaluating the health system as a whole is Semwanga's (2016) study. To capture the dynamics of the health system in Uganda, the impact of interventions on neonatal services has been investigated. System dynamics modelling has been done with the Stella program. Instead of evaluating health services from one perspective, different services and "new-born" baby care are handled together. Neonatal infant deaths were largely prevented by the education of the community on health, the free distribution of necessary materials and equipment for "new-borns", as well as the integration of motorcycle coupons. In addition to these, it has been concluded that interventions targeting socioeconomic status reduce "new-born deaths" much more than interventions targeting service delivery.

Esensoy and Carter's (2018) study investigated best practices for the treatment of patients with stroke. The 6 sectors in the Ontario health system and the patient flow between them are modelled with the Vensim program. According to the results of the study, when the best practice for treatment is done, the duration of stay of patients in all sectors has been shortened.

4.2 Literature on Agent-Based Modelling

In the study of Taboa et al. (2013), it was tried to reduce the density in the emergency service of the Sabadel hospital in Spain by making patient differentiation in the emergency room. This application is simulated with agent-based modelling. The treatment processes of the patients are divided into three groups. The verification and validation of the simulation was done by animation, degeneration tests and face-to-face interviews with hospital staff. With patient differentiation, only the very urgent patients who come to the emergency room are treated in the emergency, only the nurses take care of the others and perform the triage process, and then send them to the waiting room without taking them to the treatment room. With this method, patient waiting times could be reduced significantly.

In the study of Jaramillo et al. (2015), highly contagious disease named MRSA (Methicillin-resistant Staphylococcus Aureus) in the emergency room were modelled. The disease is transmitted by physical contact. In the conceptual model, the transmission situation between the personnel-patient, personnel-physical environment, and patient-physical environment in the emergency department where the disease can be transmitted is modelled. Contagiousness was modelled directly and indirectly. Simulations have been made on how much hand washing can reduce the risk of contamination. It has been observed that, in general, when the rate of hand washing increases, contagion in the emergency room has decreased by approximately 60%. This study was conducted with Tauli hospital staff in Spain.

In Liu's (2017) study, "What if ..." scenarios were created by calibrating with the 4-year data of the Sabadel Hospital in Barcelona. It has been investigated how to find a solution to the excessive density in ED (emergency department) when the flu epidemic occurs. Using the 4-year hospital data, the distribution of patient arrival probability was arranged by taking the opinions of the ED staff. While developing the model, the KISS (Keep it simple, stupid) principle was used. For the performance indicator, the length of stay (LoS) of the patient in ED was considered. The communication between the staff and the patient was adjusted according to the rules in the decision structure of "If-Then" modelling NetLogo program was made. Since it requires high computer and processing power, MPI (Message Passing Interface) has been used to manage the relationships between the master / worker mechanism and these processes. It has been shown that the model represents the real ED with cross validation.

In the study of Alibrahim and Wu (2018) the healthcare provider choices of patients were modelled with ABM. In this study, health service providers affiliated to Accountable Care Organizations (ACO) are discussed. The afore mentioned organizations allow individuals in America to choose the healthcare provider, while also controlling healthcare costs. These organizations bring together doctors, hospitals and other healthcare providers and work to reduce treatment errors and costs by applying the appropriate treatment to the right patient at the best time. Patients, hospitals as healthcare providers, physicians providing primary healthcare services and "Medicare" agents in the United States as payers were included in the model. Patients can change the healthcare provider determined by age, gender, income, and race. If patients want to change their service provider, they must travel 60 minutes to the other healthcare facility. Healthcare providers have features such as mortality rates, hospitalization rates and disease management program. It can also choose whether to affiliate with the ACO. If connected, they must share their cost savings with the paying institution. Paying agents calculate the returns of provider agents from these savings, in addition to the savings of providers, both affiliated and non-ACO. According to behavioural economics, epidemiological studies, cost-effectiveness, and public health literature, agent codes of conduct have been developed. It has been observed that the paying agent pays $ 320 less per year when patients choose their service provider themselves. In addition, mortality rates decreased by 0.12% and hospitalization rates decreased by 0.44%. With this study, a modelling tool was created that enables policy makers to observe the effect of patient choices and the possible consequences of policies that can be implemented in a virtual environment.

Silva et al.(2020), agent-based modelling was developed to observe the effects of the COVID-19 pandemic on public health and economy. Countries make different practices in combating epidemic disease. Protective applications were divided into seven different groups, and their possible effects were tried to be observed in the simulation. These include doing nothing, full quarantine, conditional quarantine, vertical isolation, partial isolation, the use of face masks, and finally, the use of face masks and the 50% social distance rule. In full quarantine, the worst economic scenario was realized for the lowest death rate. The most realistic scenario was the situation in which 50% social distance was applied with the use of a face mask.

4.3 Literature on Hybrid Models

Models created using two or more methods are hybrid models. Separate modelling methods have limitations. By removing these constraints with hybrid models, modelling can be made closer to reality (S. Brailsford 2007). Some models may better reflect the diversity of individual patients and healthcare professionals, and some better reflect the complexity of the healthcare system. In this study, studies using agent-based modelling, discrete event simulation and system dynamics modelling together will be examined.

In the study of Brailsford et al. (2010), which uses system dynamics and discrete event simulation methods together, it is discussed how local governments can facilitate the access of the elderly population to health services and supports. The long-term effect of a new contact centre application on this issue has been evaluated. The Hampshire Municipality call centre in England has been modelled. The centre gave advice to the elderly or referred them to appropriate health care. Vensim for SDM and Simul8 for AOS were used. In the simulation, patients who were in poor health and made the second call (those who had problems communicating at the first call) were able to get better with the advice of the authorized persons in the call centre. Thus, the number of elderly people in poor health has decreased significantly.

In the study of Taboa et al.(2011), the decision support system was developed with agent-based modelling to optimize patient waiting times in the Sabadel hospital emergency room in Spain. An ABM model has been developed that can give hospital managers the opportunity to simulate the arrangement of personnel combinations that are close to reality. In this model, doctors, nurses, registrars, and patients as active agents; the waiting rooms, treatment rooms and the announcement systems used in the emergency department were taken as passive agents. The experienced and inexperienced staff were added to the model, it was observed how long patients waited in the waiting room in different personnel combinations and how long they spent in the emergency department in total. How these waiting times are affected by different patient densities is also modelled. According to these, it was concluded that with the increase in the number of experienced staff, patient waiting times decreased at each patient density.

In the study of Dignum et al. (2020), the health, economic and social effects of the covid-19 outbreak were evaluated with agent-based modelling and SIR model. NetLogo and GUI are used. As a policy maker, the government works with epidemiologists in combating epidemic diseases, but it is important to observe the dynamic impact of many factors on interdependent and heterogeneous agents, as practices for the prevention of epidemics have serious social and economic consequences as well as health consequences. In this context, in this study, it was observed that school closures had various side effects but not positive in epidemic prevention, because most of the people had to take care of their children on weekdays more than usual and therefore go shopping for their not so urgent needs at the weekend. Since all other entertainment and socialization centres are closed here, it was preferred to go shopping. Many scenarios like this have been developed and their results have been observed. In the study, not an alternative to the models used by epidemiologists, but a complementary agent-based model has been developed in which the applied policies can be handled together with the economic and social effects. The SIR model has also been used in modelling epidemiological effects.

5. Conclusion

When healthcare services are considered as a complex system, complex system analysis tools can be used in modelling stochastic behaviour, heterogeneous units and their relationships and evaluating efficiency instead of traditional methods. Among these tools, it has been observed that system dynamics and agent-based modelling methods are used in the planning and regulation of health insurance, healthcare providers and reimbursement systems within the scope of health economics, in the optimization of personnel in emergency services, in the development of simulations for both reducing the disease risk and managing the economy in case of epidemics. ABM and SDM were frequently used to observe the results in the virtual environment before implementing the policies planned to be implemented. ABM method is superior in modelling on unit basis, on the other hand, SDM allows to evaluate the system with its stock flow approach.

Since the healthcare and healthcare market is a complex adaptive structure, classical assessment and analysis tools are insufficient to reflect the reality. Therefore, it can be said that instead of the methods using classical Newtonian mathematics and providing a single solution, the simulation methods created with today's advanced technology, in other words, methods that offer solution sets instead of a single solution are superior in evaluating the health services and health services market.

References

Alibrahim, A., and S. Wu. 2018. 'An Agent-Based Simulation Model of Patient Choice of Health Care Providers in Accountable Care Organizations'. *Health Care Management Science* 21 (1): 131–43. https://doi.org/10.1007/s10729-016-9383-1.

Atkinson, M., R. Wells, A. Page, A. Dominello, M. Haines, and A. Wilson. 2015. 'Applications of System Dynamics Modelling to Support Health Policy'. *Public Health Research and Practice* 25 (3): 1–8. https://doi.org/10.17061/phrp2531531.

Baghbanian, A., and G. Torkfar. 2012. 'Economics and Resourcing of Complex Healthcare Systems'. *Australian Health Review* 36 (4): 394–400. https://doi.org/10.1071/AH11041.

Brailsford, S. 2007. 'Proceedings of the 2007 Winter Simulation Conference S. G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, Eds.', 1436–48.

Brailsford, S. C., S. M. Desai, and J. Viana. 2010. 'Summary for Policymakers'. In *Proceedings of the 2010 Winter Simulation Conference*, edited by Intergovernmental Panel on Climate Change, 53:1–30. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781107415324.004.

Dignum, Frank, Paul Davidsson, Mijke Vander Hurk, Christian Kammler, L. G. Ludescher, René Mellema, Loïs Vanhee, et al. 2020. 'Analysing the Combined Health, Social and Economic Impacts of the Corovanvirus Pandemic Using Agent-Based Social Simulation'. *ArXiv*.

Eren, E. 2013. 'Kompleksite Iktisadı ve Ajan-Temelli Modelleme: Metodolojik Bir Yaklaşım'. http://hdl.handle.net/10419/81625www.econstor.eu.

Ersöz, F. 2008. 'Türkiye Ile OECD Ülkelerinin Sağlık Düzeyleri ve Sağlık Harcamalarının Analizi'. *İstatistikçiler Dergisi:İstatistik ve Aktüerya* 1 (2): 95–104.

Esensoy, A. V., and M. W. Carter. 2018. 'High-Fidelity Whole-System Patient Flow Modeling to Assess Health Care Transformation Policies'. *European Journal of Operational Research* 266 (1): 221–37. https://doi.org/10.1016/j.ejor.2017.09.019.

Holland, J. H. 2020. *Karmaşıklık-Karmaşık Sistemlere Kısa Bir Giriş*.

Holland, J. H., and J. H. Miller. 1991. 'American Economic Association Artificial Adaptive Agents in Economic Theory Author (s): John H . Holland and John H . Miller Source : The American Economic Review , Vol . 81 , No . 2 , Papers and Proceedings of the Hundred and Third Annual Meeting of Th'. *The American Economic Review* 81 (2): 365–70.

Jaramillo, Cecilia, Manel Taboada, Francisco Epelde, Dolores Rexachs, and Emilio Luque.

2015. 'Agent Based Model and Simulation of MRSA Transmission in Emergency Departments'. *Procedia Computer Science* 51 (1): 443–52. https://doi.org/10.1016/j.procs.2015.05.267.

Kitson, A., A. Brook, G. Harvey, Z. Jordan, R. Marshall, R. O'shea, and D. Wilson. 2018. 'Using Complexity and Network Concepts to Inform Healthcare Knowledge Translation'. *International Journal of Health Policy and Management* 7 (3): 231–43. https://doi.org/10.15171/ijhpm.2017.79.

Lane, D., C. Monefeldt, and J. Rosenhead. 2000. 'Looking in the Wrong Place for Healthcare Improvements: A System Dynamics Study of an Accident and Emergency Department'. *Journal of the Operational Research Society* 51 (5): 518–31. https://doi.org/10.1057/palgrave.jors.2600892.

Lane, D., and J. Rosenhead. 1998. 'Emergency - but No Accident - a System Dynamics Study of Casualty Waiting Times in the British NHS - CentAUR'. *Eurohealth* 4 (1): 34–36.

Lessard, C. 2007. 'Complexity and Reflexivity: Two Important Issues for Economic Evaluation in Health Care'. *Social Science and Medicine* 64 (8): 1754–65. https://doi.org/10.1016/j.socscimed.2006.12.006.

Liu, J. X., Y. Goryakin, A. Maeda, T. Bruckner, and R. Scheffler. 2017. 'Global Health Workforce Labor Market Projections for 2030'. *Human Resources for Health* 15 (1): 1–12. https://doi.org/10.1186/s12960-017-0187-2.

Liu, Pai, and Shinyi Wu. 2016. 'An Agent-Based Simulation Model to Study Accountable Care Organizations'. *Health Care Management Science* 19 (1): 89–101. https://doi.org/10.1007/s10729-014-9279-x.

Liu, Z., E. Cabrera, D. Rexachs, and E. Luque. 2014. 'A Generalized Agent-Based Model to Simulate Emergency Departments'. *The Sixth International Conference on Advances in System Simulation,* no. c: 65–70. http://www.thinkmind.org/index.php?view=article%5C&articleid=simul%5C_2014%5C_3%5C_30%5C_50128.

Phelps, Charles E. 2018. *Health Economics*. *Routledge*.

Plsek, P. 2001. 'Crossing the Quality Chasm: A New Health Care System for the 21st Century'. 2001. https://europepmc.org/books/n/nap10027/ddd00168/?extid=25057539&src=med.

Semwanga, A. R., S. Nakubulwa, and T. Adam. 2016. 'Applying a System Dynamics Modelling Approach to Explore Policy Options for Improving Neonatal Health in Uganda'. *Health Research Policy and Systems* 14 (1): 1–17. https://doi.org/10.1186/s12961-016-0101-8.

Silva, Petrônio C.L., Paulo V.C. Batista, Hélder S. Lima, Marcos A. Alves, Frederico G. Guimarães, and Rodrigo C.P. Silva. 2020. 'COVID-ABS: An Agent-Based Model of COVID-19 Epidemic to Simulate Health and Economic Effects of Social Distancing Interventions'. *Chaos, Solitons and Fractals* 139. https://doi.org/10.1016/j.chaos.2020.110088.

Taboada, Manel, Eduardo Cabrera, Francisco Epelde, Ma Luisa Iglesias, and Emilio Luque.

2013. 'Using an Agent-Based Simulation for Predicting the Effects of Patients Derivation Policies in Emergency Departments'. *Procedia Computer Science* 18: 641–50. https://doi.org/10.1016/j.procs.2013.05.228.

Taboada, Manel, Eduardo Cabrera, Ma Luisa Iglesias, Francisco Epelde, and Emilio Luque. 2011. 'An Agent-Based Decision Support System for Hospitals Emergency Departments'. *Procedia Computer Science* 4: 1870–79. https://doi.org/10.1016/j.procs.2011.04.203.

Wilensky, Uri, and William Rand. 2015. *An Introduction to Agent-Based Modeling*. *Agent Analyst*.