Institution: University of Strathclyde		
Unit of Assessment: C17 Business and Management Studies		
Title of case study: Improved patient outcomes through evidence-based decisions by Scottish and global health organisations		
Period when the underpinning research was undertaken: 2013 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Alec Morton	Professor	1 October 2013 - present
Robert Van Der Meer	Professor	1 September 1990 - present
Itamar Megiddo	Senior Lecturer	9 March 2015 - present
Susan Howick	Professor	2 October 1995 - present
Gillian Anderson	Research Associate	18 August 2014 - 25 February 2021
Period when the claimed impact occurred: August 2013 - December 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Modelling methods research at Strathclyde enabled the formulation and implementation of health care policy to improve patients' outcomes in Scotland and internationally. At national level, this strengthened service delivery in Scotland's National Health Service (NHS), through the scale-up of virtual clinics and sustained delivery of care in hospitals and care homes during the Covid-19 pandemic. Internationally, Strathclyde's research increased analytical capacity at the World Health Organisation and Global Fund leading to informed strategic allocation of development aid in support of a wide portfolio of health initiatives to reduce morbidity and mortality.

2. Underpinning research

Healthcare systems globally face challenges in seeking to improve health outcomes from avertable death and disease to reduced health budgets and operational efficiency. Since 2013 Strathclyde led research to improve modelling of healthcare systems where characteristics such as interactions between multiple stakeholders and complex constraints contribute to non-linear behaviour (changes in the output do not change in direct proportion to changes in any of the inputs). Two research strands focused on particular healthcare system problems. Morton led research to create new methods based on optimisation principles to support investment decisions by the World Health Organisation (WHO) and the Global Fund. Van Der Meer, Megiddo and Howick led methodological research on simulation models to support decision-making in local NHS organisations. Common to both research strands was the provision of improved modelling methods capable of providing better information to decision-makers.

Simulation models for healthcare operations

The simulation modelling methods (agent-based, discrete event and system dynamics) allow problem characteristics to be represented in ways relevant to a specific study and to support investigation of process and policy options before decisions are taken. Howick and co-authors examined the role of different types of simulation models, including when each is appropriate and how to mix methods [**R1**]. By creating a set of mixed method designs, informed by theory and application, the researchers identified how these designs can inform simulation methodology selection for specific projects.

Megiddo created an approach to building agent-based simulation models which considered interactions between the behaviours of populations of system actors and the non-linear characteristics of health systems. Through applications to real-world situations, including investigating the interactions between access to water and sanitation and childhood diarrheal diseases [as reported in **R2**], Megiddo demonstrated how to model these characteristics of healthcare problems as complex systems.

Van Der Meer led research, funded by NHS Scotland, to create costing models of virtual clinics based on discrete event simulation [**R3**]. A virtual clinic is a telemedicine intervention allowing patients to be assessed remotely instead of face-to-face outpatient appointments. The approach allowed micro-cost analysis to be based on explicit modelling of contextual information, which had

previously not been possible using health economic evaluation methods relying on average cost data. Findings from **R1**, **R2** and **R3** informed the methodological choices made by Strathclyde researchers to build simulation models for multiple Covid-19 projects for NHS Scotland in 2020. **R1** and **R3** provided the basis of the discrete event simulation model designed to investigate hospital ICU capacity. The agent-based approach in **R2** shaped the model built to examine policies about visiting and staff rotation for care homes. Drawing on **R1**, this model was further enhanced with elements of discrete-event simulation and systems dynamics during verification, which increased confidence in the findings.

Optimisation models for complex healthcare objectives

Since 2013, Morton has led research on cost-effectiveness analysis in global health policy in health care systems that implement 'Out-of-Pocket' approaches to provision, or where health care systems are underdeveloped. The research was motivated by collaborations with Lauer (then at the Department of Health Systems Governance and Financing at the WHO) and Borowitz (Chief Economist at the Global Fund). Morton's research addresses the shortcomings of traditional methods of economic evaluation in low- and middle-income countries (LMIC), where health financing and administration are more complex and the roles and objectives of a wider range of stakeholders require consideration. Morton's key theoretical insight was that standard cost-effectiveness analysis threshold rules imply an over-simplistic underlying mathematical optimisation model for the problem, and that by generalising this model to accommodate features of the real-world problem (e.g. equity, additional constraints, existing multiple players) can lead to generalised cost-effectiveness threshold rules. Working with LSE, Imperial College and Erasmus University, Morton created theoretical models based on mathematical programming [**R4**], game theory [**R5**] and dual pricing [**R6**] to describe, contextualise and generalise cost-effectiveness methods to healthcare in settings where donors and countries have potentially competing objectives, and constraints imposed by asset-specific investments can distort cost-effectiveness estimates. The mathematical model and decomposability results showed that funding for health system strengthening can be prioritised independently of other programmes if appropriate factors are measured [**R4**]. Morton et al.'s modelling of co-financing between donor and recipient country as a leader-follower game allowed optimal strategies for investments in health services to be determined [**R5**]. A theoretical model created by Morton and co-authors describing the optimal allocation of the health care budget in settings with healthcare input constraints [**R6**] showed that adjusting the price conserved scarce human resources. By providing methods that capture social features of the problem, Morton's research allows for the development of a descriptive schema for understanding and interpreting economic evaluations. The research further underpins a socio-technical analytical framework [**S8**]. This framework demonstrates how economic evaluations can be performed, and how they can be interpreted, to preserve core principles that motivate and ground economic evaluations, while at the same time providing a road map for extending their use in other settings.

3. References to the research (Strathclyde affiliated researchers in **bold**)

R1 J. Morgan, **S. Howick**, **V. Belton** (2017) A toolkit of designs for mixing discrete event simulation and systems dynamics, *European Journal of Operational Research*, 257(3): 907-918 https://doi.org/10.1016/j.ejor.2016.08.016 [REF2]

R2 A. Nandi, I. **Megiddo**, A. Ashok et al. (2017) Reduced burden of childhood diarrheal diseases through increased access to water and sanitation in India: A modeling analysis, *Social Science & Medicine*, 180: 181–92. http://dx.doi.org/10.1016/j.socscimed.2016.08.049 (5 authors)

R3 **G. Anderson**, P. Jenkins, D. McDonald, **R. Van Der Meer**, **A. Morton** et al. (2017) Cost comparison of orthopaedic fracture pathways using discrete event simulation in a Glasgow hospital, *BMJ Open*, 7:e014509 http://dx.doi.org/10.1136/bmjopen-2016-014509 (7 authors)

R4 **A. Morton**, R. Thomas, P. Smith (2016) Decision rules for allocation of finances to health systems strengthening, *Journal of Health Economics,* 49: 97-108 https://doi.org/10.1016/j.jhealeco.2016.06.001

R5 **A. Morton**, **A. Arulselvan**, R. Thomas (2018) Allocation rules for global donors, *Journal of Health Economics*, 58: 67-75 https://dx.doi.org/10.1016/j.jhealeco.2018.02.003 [REF2]

R6 P. van Baal, **A. Morton**, J.L. Severens (2018) Health care input constraints and cost effectiveness analysis decision rules, *Social Science & Medicine*, 200: 59-64 https://doi.org/10.1016/j.socscimed.2018.01.026

Notes on the quality of research: All outputs are published in respected peer-reviewed journals. This research has been supported with competitively-awarded funding totalling GBP1,348,688 from funders including: European Commission (Morton (PI), DRIVE-AB: Driving Re-investment in R&D and Responsible Antibiotic Use, 01/10/14-30/09/17, GBP483,036); UK Department of Health and Social Care (e.g. HAPIOR, GBP223,061, 01/06/17-31/05/20); and Lanarkshire NHS (Burns (PI), Maguire (CI) van der Meer (CI), Social Innovation Programme for Health and Wellbeing, 01/02/19-30/04/20, GBP195,000).

4. Details of the impact

By creating new methods and providing the basis of a coherent framework for evaluating cost-effectiveness, Strathclyde's research improved analytical capacity at the WHO and the Global Fund to inform better healthcare resource allocation. By developing simulation modelling approaches, Strathclyde's research informed analysis that translated results into actionable evidence to NHS Scotland. Together, the Strathclyde research enabled both national and global decision-makers to formulate and implement policy to improve patient care and outcomes.

Influenced healthcare operations to improve patient care in NHS Scotland

A key challenge for NHS Scotland since 2013 has been the pressure on outpatient appointments, numbering around 4.5 million annually, but not all appointments need to be face-to-face. Working with the Scottish Government's Whole System Flow Team, Strathclyde researchers modelled clinical and patient pathways and established an evidence base for new approaches to care. Van Der Meer led the creation of a simulation model to assess the cost-effectiveness of a virtual fracture clinic [**R1**] which, according to the National Clinical Director, can *'substantially reduce outpatient attendances in orthopaedic trauma care and free up resources to be used for patient services elsewhere in the healthcare system'* [**S1**]. The Chief Operating Officer for NHS Scotland reported benefits of this work in 2014-17 for patients and the NHS: *'The pioneering application of the Strathclyde research in the Glasgow Royal Infirmary has resulted in a 65% reduction in the number of first outpatient face-to-face attendances in orthopaedics. Based on detailed feedback from service users, patients are satisfied with the new pathway, the information provided and the outcome of their injuries. The overall cost per patient of the virtual pathway was GBP22.84 per patient compared with GBP36.81 for the traditional (non-virtual) pathway, a saving of 38% – which should be seen in the context of more than 120,000 patients per year requiring non-operative trauma care in Scotland'* [**S2**]. Additionally, the Strathclyde modelling of the virtual fracture clinic at Glasgow Royal Infirmary supported the scale up of this service process redesign across the UK, and in the Republic of Ireland, the Netherlands, Norway, New Zealand and Australia [**S3**]. Taking Ireland as an example, to date 22 hospitals have fully implemented the principles of fracture clinic redesign [**S3**]. In order to extend reach, the Strathclyde team developed research-led training, delivered between 2016-2019, to *'provide NHS Scotland staff with the modelling tools required to implement locally relevant plans for service redesign',* and 82 alumni of this course now lead projects across NHS Scotland [**S1**]. According to the National Clinical Director for Scotland, *'The challenges of pathway redesign have … never been more important'* and the work of *'Robert Van Der Meer and colleagues is destined to play a key supporting role in our plan to design and deliver a sustainable health system as we move into 2021 and beyond'* [**S1**].

Two strands of work with NHS Scotland led to improved patient care in hospital and care homes during the Covid-19 pandemic in 2020. Firstly, since March 2020, the researchers built discrete-event simulation models to forecast hospital capacity [**S4**] [**R1**, **R3**]. Recognising the importance of limited ICU beds, the Scottish Government and NHS Scotland were able to use the information generated by Van Der Meer's modelling of critical care bed requirements for Covid-19 patients in NHS Lanarkshire to support timely preparations for the April 2020 peak of the pandemic in Scotland. According to the Chief Executive of NHS Lanarkshire, Strathclyde's models informed the decision to convert *'theatre capacity to double* [the ICU] *capacity'* from 30 to 60 beds *'during the acute phase of the pandemic'* [**S5**]. Understanding the timing of critical care bed requirements for Covid-19 meant that NHS Lanarkshire could balance care between Covid-19 and non-Covid-19 patients. This enabled non-Covid-19 procedures to proceed earlier than previously planned: since *'a stay in ICU is literally the difference between life and death for a critically ill patient'* [**S5**], the work of Strathclyde researchers helped by identifying where NHS Lanarkshire were *'able to spare ICU capacity in order to admit and operate on high-priority non-Covid patients'* [**S5**]. The Chief Executive of NHS Lanarkshire further reported that *'the Strathclyde forecasting work has*

improved our ability to provide our frontline staff with predictability about work patterns and the operating environment – a significant contribution at a time of huge stress and uncertainty' [S5].

Secondly, an agent-based model built by Strathclyde researchers, drawing on R1 and R2, informed the management of patients in care homes in Lanarkshire. Approximately 40% of UK Covid-19 fatalities can be attributed to deaths in care homes. Strathclyde worked with staff in the local authority and met regularly with healthcare managers to align the creation of the agent-based simulation model with the challenges faced by the care sector. The National Clinical Advisor for Ageing and Health in Scotland recognised that Strathclyde's modelling was *'instrumental for making evidence-informed decisions and policy that likely saved lives'* [S6]. Decisions taken on the basis of Strathclyde's model were: increased testing for staff and reduced testing for residents; development of individual risk-based visitation plans; and creation of smaller units in larger care homes [S5]. The National Clinical Advisor said that changing the testing strategy *'saved approximately GBP8,400,000 in Scotland through December 2020 compared to the strategy in England to test residents every twenty-eight days, freeing up resources for more effective interventions'* and *'potentially averted an estimated 9,250 Covid-19 cases among the 37,000 care home residents in Scotland over a period of 3 months'* [S6]. The NHS Lanarkshire Chief Executive said that the results from Strathclyde's modelling was *'more timely and easier to justify than guidance from central government. In summary, the Strathclyde research has provided added value on top of the existing sources of advice available to us and helped us keep residents safe from harm, at the same time as implementing what are necessarily burdensome and disruptive safeguarding measures in a way which is risk-based and proportionate'* [S5].

Influenced economic evaluation practice in global health organisations

The World Health Organization (WHO) appraisal practice was improved since 2016 by adopting a socio-technical analytical framework underpinned by Morton's theoretical research. In 2020 the WHO chose to publish a public working paper [S8] co-authored by Morton and referencing [R4, R5]. This paper, based on Morton and Lauer's research *'was developed at WHO in the department of Health Systems Governance and Financing between 2016 and 2019 while being tested with staff in a number of WHO programmes'* [S8].

By enhancing the analytical capacity at the WHO, the research influenced WHO policy making and thereby improved health outcomes by enabling the economic effects of high-profile investment cases to be better evaluated. Without such analysis, the potential consequences of specific investment asks would not have been included in decision making. The Team Lead for Value of Vaccines, Modeling and Economics at the WHO says of this framework that: *'No single publication that I can name has been more influential in impacting positively on the quality of economic evaluation…than the paper by Morton and Lauer* [which] *has been useful in assisting both scientists and policymakers to integrate diverse disciplinary perspectives in formulating global recommendations on vaccine policy'* [S7a]. This framework [S8] provided the intellectual basis for investment cases for improved prevention and control of noncommunicable diseases (NCD) and improved global access to vaccination programmes in the period 2015-2020. A WHO analyst confirmed the framework's impact and reach: *'We applied these concepts in our work on a global investment case for noncommunicable diseases… as well as in approximately 30 country investment cases for NCDs that have since been done under the auspices of WHO'* [S7b]. The countries affected include Barbados, Belarus, Fiji, Jamaica, Kyrgyzstan, Mongolia, Saudi Arabia and Uzbekistan, where, the WHO analyst said, *'country investment cases… have proved to be important in mobilizing political support for the prevention and control of NCDs'* [S7b].

The economic evaluation process used by Gavi, the global vaccines alliance, was improved by Strathclyde research. Gavi consolidates development aid for vaccines in LMIC from multiple government and philanthropic sources and distributes them based on WHO technical advice. Gavi protect nearly half of the world's children through vaccination; between 2016 and 2019, it immunised 259,000,000 children, and prevented an estimated 1,500,000 deaths in 2019. The Executive Secretary of the WHO Immunization and Vaccine-related Implementation Advisory Committee (IVIR-AC), recognised the importance of economic evaluation for WHO strategy: *'Economic evaluation is an important aspect…considered by the IVIR-AC in its recommendations to the WHO Strategic Advisory Group of Experts on Immunization, which is the highest global policymaking body for vaccines'* [S7a]. The role of the framework [S8] in this context was acknowledged by the Executive Secretary of the IVIR-AC*: 'I have had several recent occasions to*

use the work of Morton and Lauer' [**S7a**]. The framework is now being incorporated formally into a policy commentary on the Full Value of Vaccines Assessment [**S7a**].

Strathclyde research was taken up by WHO officials. According to the Unit Head for Blindness and Deafness Prevention, Disability and Rehabilitation, *'the work of Morton and Lauer has been useful in helping us to translate to policy-makers the impact of discrete health gains onto a set of broader social goals'* [**S7c**]. These include investment cases for improved assistive technologies and deafness prevention which were adopted by the World Health Assembly in 2017/18 [**S9a,b**]. Morton and Lauer's research [**S8**] also provided the basis for *A Healthier Humanity: The WHO Investment Case for 2019-23* [**S7c**]. According to an Economic Analyst involved, *'the concepts contained in the What counts in economic evaluations in health? discussion paper were critical in defining the accounting framework for this flagship report'* [**S7b**]. Furthermore, '*this work continues to underpin ongoing investment cases at the global level, including for the elimination of cervical cancer, cancer treatment, hearing loss and rehabilitation programmes amongst others, where it provides critical methodological support and legitimacy'* [**S7b**].

The Global Fund invests around USD4,000,000,000 billion a year to support programs run by local experts in countries and communities most in need. In 2014, *'the Global Fund contracted with Professor Morton…as part of an international team to advise on the best way to use decision analysis techniques to develop and appraise the cost-effectiveness of country plans for tackling AIDS, TB submitted to Global Fund'* [**S10**]. The team included internationally recognised researchers in infectious disease modelling from Imperial College London, Johns Hopkins, and the Swiss Tropical and Public Health Institute in Basel, with Morton contributing as an expert on decision making and economic aspects. According to the Chief Health Economist of the Global Fund, the engagement with Morton *'positively contributed to the development of national strategic plans at country level and the robustness of countries' case for support for funding'* [**S10**]. The use of Morton's framework by the Global Fund supported policy-makers and experts in Bangladesh, Mozambique and Sudan in allocating resource totalling USD779,000,000 (01-2019) in the period 2017-19 [**S10**]. Positive feedback on the framework was received from in-country partners of the Global Fund and it was welcomed by officials from the beneficiary counties. For example, the Sudanese Ministry of Health official said, *'we feel that it will add to the TB programme a lot'* [**S10**]. In addition, Morton's modelling methods helped the Global Fund to ensure *'that equity and human rights issues are given appropriate priority in country's plans,* which is a priority for funders such as the UK Department for International Development (DFID) [**S10**]. Finally, Morton's research [**R5**] influenced the Global Fund's co-financing policy by providing a justifiable and intuitive rationale for cost-sharing between donor and recipient countries [**S10**]. Going forward, the Global Fund *'are continuing to work to further develop and codify good practice'* in the use of the framework [**S10**].

5. Sources to corroborate the impact

S1 Factual statement from National Clinical Director, Healthcare Quality and Improvement Directorate, Scottish Government, dated 10/03/20.

S2 Factual statement from Chief Operating Officer NHS Scotland and Director of Delivery and Resilience, dated 23/02/21.

S3 Extracts from Fracture Clinics for the Future website: http://www.fractureclinicredesign.org.

S4 Article in Impact Magazine on Predicting Critical Care Needs during a Pandemic, pp.7-10.

S5 Factual statement from Chief Executive, NHS Lanarkshire, dated 09/02/21.

S6 Factual statement from National Clinical Advisor for Ageing and Health to the Chief Medical Officer for Scotland (SAGE representative), dated 10/02/21.

S7 Factual statements from the World Health Organization: **a.** Team Lead, Value of Vaccines, Modeling and Economics, Department of Vaccines, Biologicals and Immunization, dated 28/05/20; **b.** Economic Analyst, Health Systems Governance and Financing, dated 28/06/20; **c.** Unit Head, Blindness and Deafness Prevention, Disability and Rehabilitation, dated 28/05/20.

S8 WHO (2020) Health Financing Working Paper No.18.

S9 WHO documentation: **a.** WHO Investment Case: Improving access to assistive technology, WHA 71.8, 26/05/18; **b.** WHO Investment Case: Prevention of deadness and hearing loss, WHA 70.13, 31/05/17; **c.** WHO (2018) A Healthier Humanity: The WHO Investment Case for 2019-23.

S10 Factual statement, Chief Health Economist, The Global Fund, dated 14/01/19.