Systems Research and Behavioral Science
Syst. Res **35,** 759–775 (2018)
Published online 28 June 2018 in Wiley Online Library
(wileyonlinelibrary.com) **DOI**: 10.1002/sres.2517

■ *Research Paper*

Mapping the Dynamic Complexity of Chronic Disease Care in Singapore: Using Group Model Building in Knowledge Elicitation

John P. Ansah[1]*, David B. Matchar[1,2], Victoria Koh[1] and Lukas Schoenenberger[3]

[1] *Signature Program in Health Services and Systems Research, Duke-NUS Medical School, Singapore, Singapore*
[2] *Department of Medicine, Duke University Medical Center, Durham, NC, USA*
[3] *Faculty of Business and Economics, University of Basel, Basel, Switzerland*

This study describes a group model building exercise that aims to develop a deeper understanding of the dynamic complexity of chronic disease care delivery within a primary care setting in Singapore, leveraging on the insights of stakeholders with personal and institutional knowledge of the health care system. A group model building exercise, which included 50 stakeholders, was used to develop the qualitative model. The qualitative model helped to bring a feedback perspective to understanding the dynamic complexity of chronic disease care delivery. The feedback perspective helped in identifying the systemic issues within chronic disease care delivery, which has the potential to inform system-wide interventions and policies to improve health. Enhancing chronic care in Singapore will require an enhancement of both the capacity and capability of the primary care sector. © 2018 John Wiley & Sons, Ltd.

Keywords primary care; health services; health policy; group model building; dynamic complexity

INTRODUCTION

Singapore, like many other countries, is aging rapidly. The resident population aged 65 years and older, currently standing at 460 000 or 11.8% of the total resident population, has risen 64.4% over the last 10 years (Singapore Department of Statistics, 2015; Singapore Department of Statistics, 2016). Furthermore, this number is projected to reach 900 000 in the year 2030 (National Population and Talent Division, 2012).

*Correspondence to: John P. Ansah, Health Services and Systems Research Program, Duke-NUS Medical School, 8 College Road, Singapore 169857, Singapore.
E-mail: john.ansah@duke-nus.edu.sg

Received 11 May 2017
Accepted 29 April 2018

Accompanying this demographic shift is a growing number of people with illnesses requiring chronic care, particularly those with multiple and complex conditions. The prevalence of diabetes mellitus alone stood at 11.3% in 2010, up from only 9% in 1998 (Ministry of Health, 2015a). Such conditions, if inadequately managed, can become complex as complications manifest. Consequently, demand for costly health services such as specialist outpatient clinic (SOC) visits and emergency department (ED) care increases. As a result, the acute hospitals and specialist services that have been the focus of a health system designed for a younger population needing episodic and disease-oriented care have been showing signs of systemic stress (Ministry of Health, 2012). This is evident in the high bed occupancy rates in acute hospitals (Lam, 2014, Ministry of Health, 2016a), overburdened SOCs (Ministry of Health, 2001), increasing ED utilization (Anantharaman, 2008, Schoenenberger *et al*., 2016), long waiting times for admission to acute hospital wards (Ministry of Health, 2016b) and workforce shortages (Kang and Leong, 2012, Ministry of Health, 2012). Hospital admissions due to diabetes, for instance, are much higher in Singapore (432 per 100 000 population) than in countries such as the United Kingdom (64) or the United States (149) (OECD, 2016). It is becoming evident to clinical and public policy leaders that change is needed in outpatient services for a new demographic reality.

To adapt to the evolving needs of a population with chronic diseases, many countries have been reassessing their health care system to focus on chronic disease care (World Health Organization, 2002). This is also the case in Singapore; currently, although the private general practitioner (GP) clinics see the bulk of primary care attendees (81%), there is an apparent imbalance in chronic disease care delivery between the private and public sectors. With 80% of the primary care capacity—number of GPs—the private GPs see 55% of patients with chronic diseases and the remaining 45% are seen by the public polyclinics, with 20% capacity (Sng, 2010). This imbalance is attributed to the health care financing model in Singapore that encourages the transition to public services as needs become more complex (Lam, 2013). In response to these observations, significant initiatives have been undertaken in recent years to strengthen the primary care sector in providing care for patients with complex chronic diseases. Innovative care models such as family medicine clinics and community health centres have been piloted to assess their likely impact on the uptake of private GP services by chronic disease patients (Ministry of Health, 2015b).

Thus, with appreciation of the dynamic complexity of chronic disease care delivery (Siokou *et al*., 2014), there is a growing need to understand the systemic causes of the current chronic disease care delivery trends. This is important because system-level interventions are likely to be expensive, may have unintended consequences and are potentially difficult to unwind once put in place; hence, it is prudent to understand the systemic causes and dynamics of such interventions before implementing them. To date, most research on chronic disease care delivery has been constrained by linear models. Group model building (GMB) is a participatory approach that is widely used to build capacity of stakeholders to address complex problems (Siokou *et al*., 2014). GMB, which uses systems science methodology of System Dynamics as a foundation, has a unique advantage for studying chronic disease care delivery in comparison with traditional analytic approaches: it focuses on complex dynamic interactions between different parts of the system and offers a framework for interdisciplinary and transdisciplinary approaches to address complex problems. In this paper, we present a qualitative system dynamics model of chronic disease care delivery developed in a GMB setting. This qualitative system dynamics model builds upon prior efforts to model chronic disease care delivery (Hirsch and Homer, 2004, Homer *et al*., 2007, Loyo *et al*., 2013).

Application of Group Model Building

Chronic disease care delivery is characterized by both detail complexity and dynamic complexity. The former refers to the complexity due to multiple stakeholders within the system—

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

policymakers, providers, patients, funders and educators—each with disparate interests (Senge, 1990, Ellis, 2010, Homa *et al*., 2015). The latter refers to complexity arising from interactions among the stakeholders, made more pertinent due to the public and private division, together with multiple payers in the system (Sterman, 2001). In order to gain a thorough understanding of the complexities of chronic disease care in the primary care system, various stakeholders have to be engaged simultaneously so that different perspectives can be consolidated in a single overarching framework. It is also important that the conversation is not dominated by a single view and that all stakeholders can participate in the conversation as well as share their knowledge and perspective freely. This is particularly important because it is often intuitive to reduce complex problems into smaller, isolated components and explore them in detail. This may be counter-effective in understanding the system as a whole as it neglects the emergent behavior of its multiple interacting parts.

The use of a qualitative system dynamics approach in a GMB setting has been found to be a useful approach in engaging different stakeholders in developing a deeper understanding of difficult and complex problems (Vennix, 1996). Such problems may be difficult because they are complicated and involve many moving parts and details, or complex because they involve many potential interactions and explanatory pathways (Hovmand, 2014). GMB refers to a bundle of techniques used to develop systems models, working directly with stakeholder groups, to gain a whole systems perspective. Models developed with stakeholders are then used as an explicit representation of the cause-and-effect relationships that result in desirable outcomes to gain a comprehensive insight of the complexity (Richardson *et al*., 2007). Engaging stakeholders in GMB ensures that issues and insights into a problem can be captured and represented in a coherent and comprehensive framework to increase the understanding of a system as a whole (Forrester, 1961, Sterman, 2000, Homer and Hirsch, 2006, Scott *et al*., 2016). In addition, the resultant model may be used as a boundary object—that is, a representation of the problem that serves to facilitate further discussion among other stakeholders, bringing about a comprehensive whole systems perspective (Wenger, 1998). Moreover, GMB could be considered as a potential system intervention as stakeholders develop new insights.

Although GMB is an underutilized methodology in health care research, a plethora of academic literature supports its value for engaging stakeholders in framing and addressing complex dynamic policy questions. Vennix and Gubbels (1992) used the GMB method to develop a conceptual model to investigate the gradual but persistent rise in health care costs in a regional Dutch health care system. Homa *et al*. (2015) employed a participatory GMB process involving patients, caregivers and primary care clinicians to investigate the mechanisms that might account for the effect of primary care beyond disease-specific care. Another study used an agent-based computer simulation model developed with GMB to test plausible hypotheses about the primary care system (Homa *et al*., 2015). Similarly, Allender and colleagues (2015) used GMB to develop a causal loop diagram of the systemic causes of childhood obesity, to facilitate planning of obesity prevention responses.

METHODS

Figure 1 shows the stakeholder engagement process. First, 75 stakeholders with deeply personal and institutional knowledge of chronic disease care delivery within the primary care sector in Singapore were identified by the Health Services and Systems Research Department, Duke-National University of Singapore and primary care experts in the Singapore General Hospital health cluster, to work with researchers in developing a deeper understanding of the complex dynamics of chronic disease care delivery and identifying leverage points to plan interventions (Forrester, 1961, Sterman, 2000, Homer and Hirsch, 2006, Scott *et al*., 2016). Fifty stakeholders responded to the invitation and participated, they included private GPs (4), polyclinic doctors (3), and medical educators (5), representatives

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

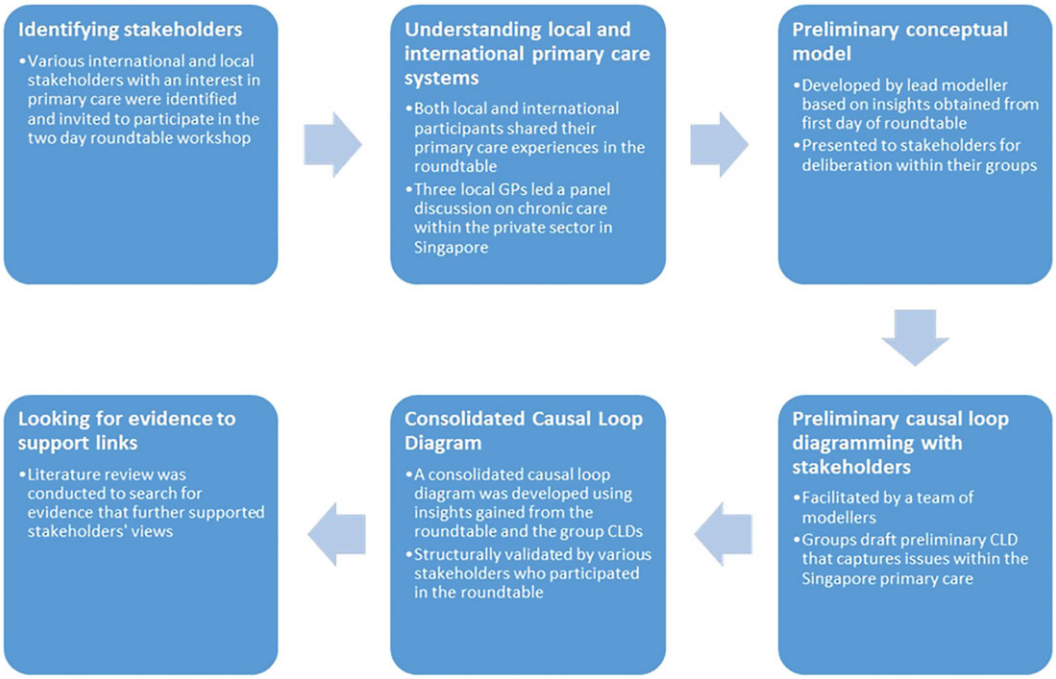

Figure 1 Workflow of model development. [Colour figure can be viewed at wileyonlinelibrary.com]

from hospitals (15) and ministries (3) as well as academic health services researchers (20).

Following consent from stakeholders, a 2-day roundtable workshop was organized. For the first day, 11 presentations covering a wide range of experience on enhanced primary and chronic disease care in the United States, United Kingdom and Singapore were shared by the presenters, each followed by a comprehensive discussion. Based on the presentations and discussions, a preliminary qualitative conceptual model was developed by an experienced GMB practitioner as a concept model for the stakeholder discussion for day two. On the second day of the workshop, the concept model was presented to the stakeholders for deliberation. A team composing of facilitators, modellers, recorders and reflectors facilitated the discussion process, through which the stakeholders deliberated on the preliminary concept model to negotiate differences in the problem conceptualization, model assumptions and structure. After an initial discussion, the stakeholders were divided into four groups to deliberate on three questions: (i) what are the options for models of enhanced primary care in Singapore?, (ii) what are the desired scenarios for enhanced primary care in Singapore? and (iii) how can the desired scenarios be implemented in Singapore? All four groups identified various aspects of enhanced primary care in Singapore from the perspectives of patients, providers and the government. The group discussions ranged from the role of patient satisfaction and engagement, changes in the model of primary care delivery in relation to changes in technology and the quality and extent of services, to the expectations of the public and the perceived value of enhanced primary care services. Each group then captured their insights in a qualitative system dynamics model. The models were then presented to all the participants and examined in an often highly animated plenary discussion. Each group focused on specific areas of interest. Of particular importance in the discussion was the role of incentives and choices, both among the patients seeking care from different providers and the GPs focusing on specific areas of practice (e.g. simple episodic care vs. chronic care vs. aesthetics) and pursuing additional training or joining a group practice.

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

After the 2-day roundtable workshop, the researchers merged all the qualitative models produced. Supported by evidence from the literature (Table A1), the merged model (Figure 6) was refined in an iterative process that involved sending the merged model to stakeholders for comments until the model was able to satisfy requirements concerning its realism and clarity, and its ability to capture important issues relating to the model's purpose of capturing the dynamics of chronic care in Singapore. The process of establishing model realism and clarity used the Categories of Legitimate Reservation rules (Noreen *et al*., 1995; Dettmer, 1997). The Categories of Legitimate Reservation constitutes a framework of eight specific tests, or proofs, used to verify cause and effect logic. They are clarity, entity existence, causality existence, cause insufficiency, additional cause, cause–effect reversal, predicted effect existence and tautology. In addition, an extensive literature review was conducted to find evidence to support the hypothesized links in the model.

Qualitative Model of Chronic Disease Care Delivery

The chronic disease care delivery model is a qualitative system dynamics model with stocks, flows and feedback loops describing the interactions between different components of the system. The model consists of five interrelated parts: population health, health care cost, provider work life, patient experience, and GP networks and relationships. Because the model structure for each venue of care (GP clinics, Polyclinics and SOCs) were similar, they are not specifically represented in the model to avoid repetition and to improve readability. In the model, stocks (rectangular boxes) represent accumulation and characterize the state of the system. Flows (the double lines with a valve) illustrate the rate of change of stocks and are controlled by valves that regulate flows, whereas arrows are the connectors or causal links. Arrows indicate the direction of a causal relationship, positive ('+') and negative ('−') signs show the polarity of relationships. A positive relationship implies that an increase in the cause variable will result in an increase in the effect variable, all things being equal. A negative relationship indicates that an increase in the cause variable will result in a decrease in the effect variable, all things being equal. A set of parallel lines over an arrow signifies a significant time lag between cause and effect variables (Schoenenberger *et al*., 2016). This model builds upon prior quantitative system dynamics models for chronic disease care. Hirsch and Homer (2004) used a system dynamics model to study the dynamics of health care services for improving chronic illness management. Homer *et al*. (2007) used the same methodology to understand the upstream and downstream impacts of chronic illness interventions. Loyo *et al*. (2013) used a system dynamics model to study how to align community action to address chronic disease risks.

Population Health

The population health sector in Figure 2 shows the segmentation of the population (Lynn *et al*., 2007) into four health states: (i) healthy; (ii) chronic asymptomatic; (iii) chronic stable but moderately/seriously symptomatic and (iv) chronic with serious exacerbation. The healthy segment of the population does not have known risk factors or chronic diseases, whereas the chronic asymptomatic segment has one or more chronic diseases but no symptoms that would themselves lead to care seeking. Those in the chronic symptomatic segment have symptomatic chronic conditions not requiring frequent acute care, which is operationally defined as three or more ED or acute hospital visits in 6 months, or requiring care by more than one outpatient provider. Lastly, patients with limited reserve and serious exacerbations are those with chronic diseases resulting in complications and frequent admissions to hospitals. Population segmentation into health states has been found to facilitate service delivery and planning of care resources (Lynn *et al*., 2007). The transition from one health state to another (for both progression and regression of complications of chronic diseases) has been found to be different across health states (Denton and Spencer, 2015) and is affected

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

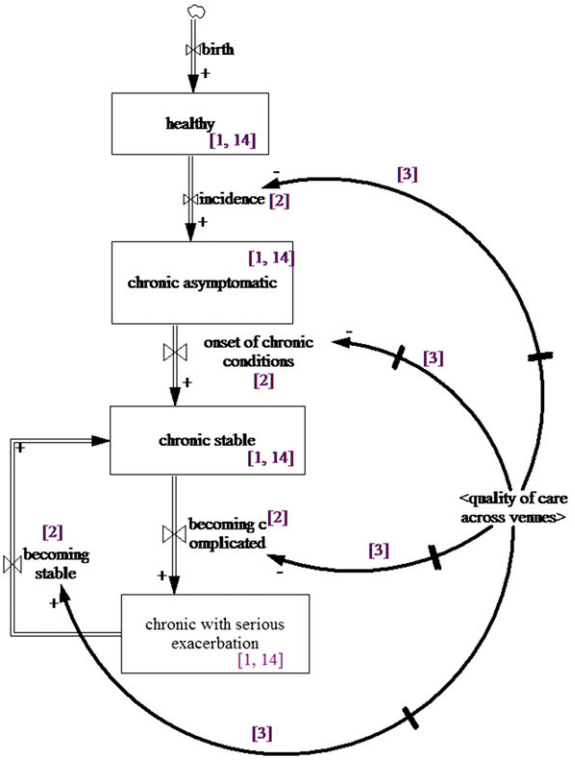

Figure 2 Population health sector. [Colour figure can be viewed at wileyonlinelibrary.com]

by the quality of chronic disease care (Derose and Petitti, 2003). Thus, the quality of care produced by the health care system influences population health (the number of individuals in each health state) and the probability of transitioning between states. For the purpose of this model, quality of care for individuals in a particular segment is assumed to vary across care venues (GPs, Polyclinics and SOCs). For instance, chronic asymptomatic patients would be best treated at enhanced primary care venues, followed by polyclinics. Chronic stable patients will receive the appropriate care they need at enhanced primary care venues and SOCs instead of polyclinics and private GPs. Patients with chronic diseases with serious exacerbations are best treated in SOCs, followed by enhanced primary care.

Health Care Cost

By providing the adequate care that each segment of the population requires, the total cost of care (Figure 3) is expected to decrease as positive health outcomes are generated. It is important to understand that health care cost may increase in the short to medium term—as improved or—in some cases—more care is provided. However, over time, health care cost is expected to decrease as population health improves, leading to less cost relative to what it would have been.

Patient Experience

The patient experience sector (Figure 4) captures the dynamics of the factors influencing patient experience across care venues, which in turn affects their care seeking behavior. Change in patient satisfaction with care is influenced by waiting time for care (Anderson *et al*., 2007), quality of the doctor–patient relationship (Williams *et al*., 1998) and perceived quality of care by patients (Alrubaiee and Alkaa'ida, 2011). Waiting time for care is influenced by the number of

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

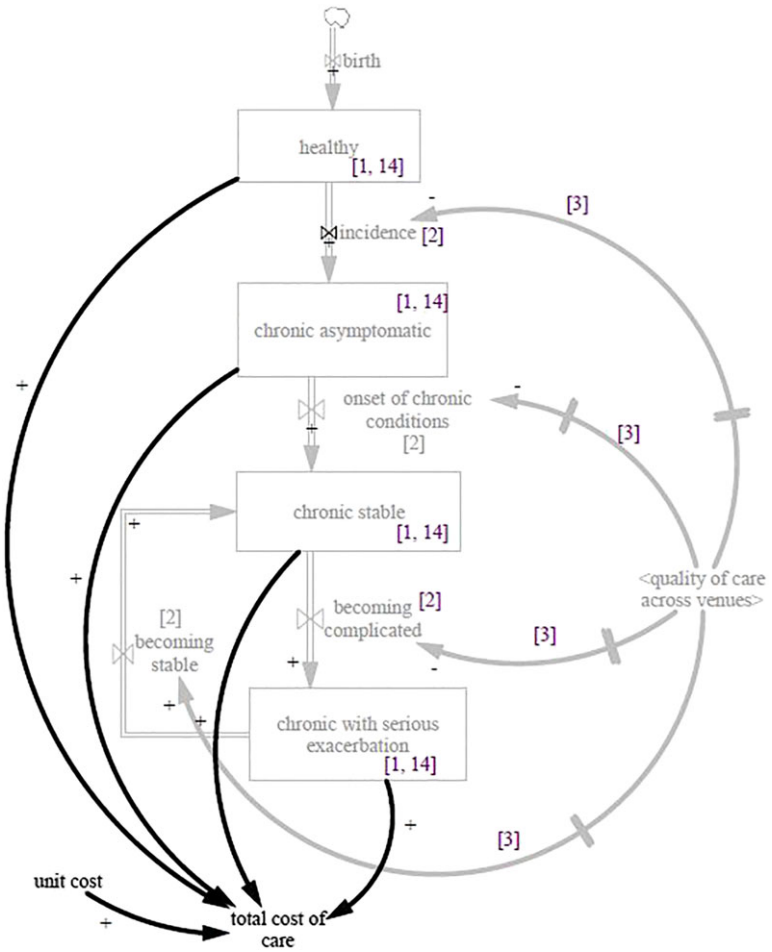

Figure 3 Adding health care cost sector. [Colour figure can be viewed at wileyonlinelibrary.com]

doctors available to provide chronic care and demand for chronic care by patients (Murray, 2007). The length of consultation (Howie *et al*., 1991) and frequency of seeing the same doctor (Hjortdahl and Lærum, 1992) are the factors that influence the doctor–patient relationship. The frequency of seeing the same doctor is determined by a visit-to-doctor ratio. Within the Singapore health care system, the frequency of seeing the same doctor is assumed to be high for single practice GPs, intermediate for group practice GPs and SOCs, and low for polyclinics. Thus, the length of consultation is determined by patient visits and number of doctors available to provide care. Perceived quality of care is assumed to be delayed relative to the actual quality of care, due to the time it takes for patients to observe a change in the quality of care.

The feedback loop B1 depicts how attractiveness of care venue translates into a high number of patient visits, which then contributes to poor patient satisfaction in the form of long waiting times for patients seeking care. In contrast, good patient satisfaction coupled with favourable out-of-pocket cost contributes to the attractiveness of care venues (Kulu-Glasgow *et al*., 1998, Himmel *et al*., 2000, Sloan and Kasper, 2008), which could lead to increased patient visits (Zastowny *et al*., 1989) and longer waiting times, which in turn, deplete patient satisfaction if without concurrent increase in capacity (the number of doctors available to provide care).

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

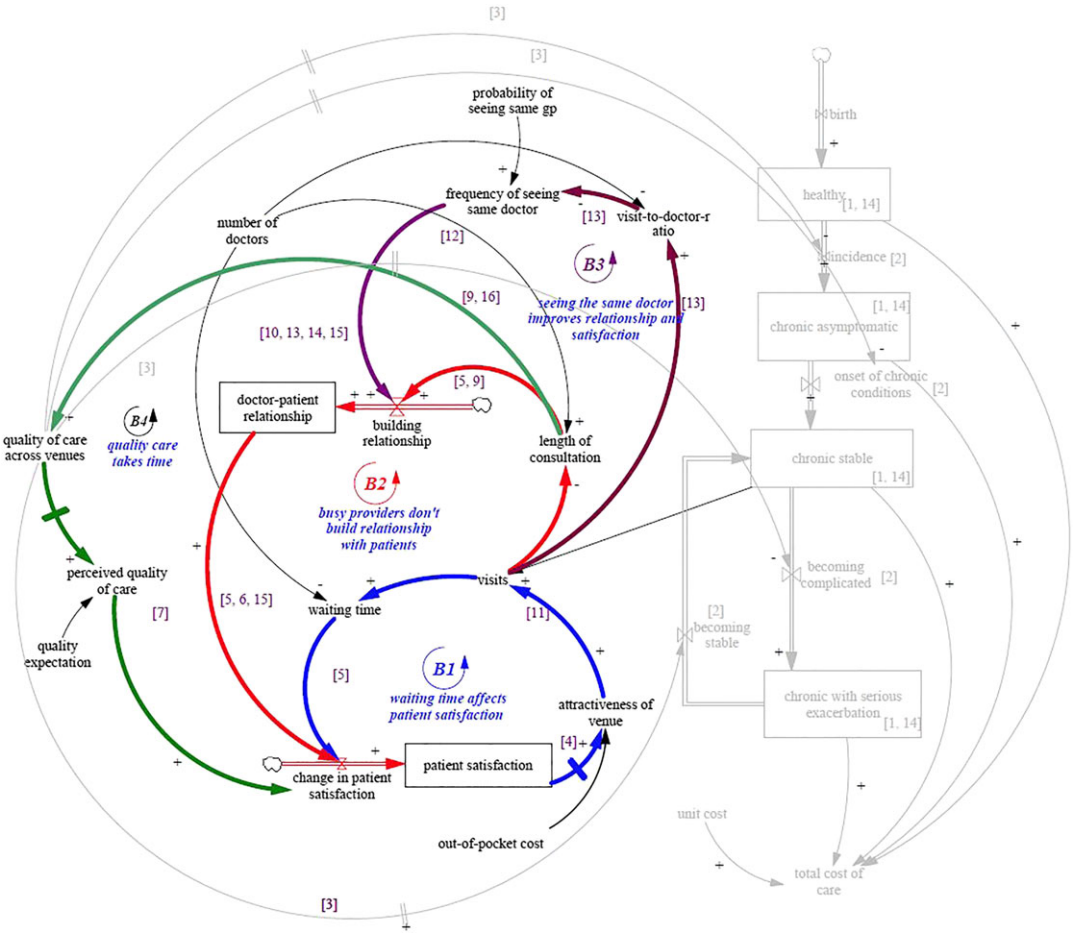

Figure 4 Adding patient experience and provider work life sectors. [Colour figure can be viewed at wileyonlinelibrary.com]

Provider Work Life

The provider work life sector (Figure 4) depicts factors that influence the workload of care providers, which can affect their preference for the provision of certain types of care and also affect patient experience. The feedback loop B2 shows how the length of consultation affects the doctor–patient relationship and patient satisfaction. While patient visits increase as a result of high patient satisfaction, length of consultation is assumed to decrease to accommodate the increased patient volume; consequently, relationship building between patient and the doctor is affected (Campbell *et al.*, 2001b, Mandel *et al.*, 2003) due to the limited time a patient spends with a doctor, which in turn, reduces patient satisfaction.

Feedback loop B3 describes how the frequency of seeing the same doctor for chronic care impacts the doctor–patient relationship. As depicted in feedback loop B3, an increase in patient visits, all else being equal, will cause the visit-to-doctor ratio to increase, which in turn, will reduce the probability that a patient will always be seen by the same doctor for his or her chronic disease care. The use of multiple doctors for chronic disease care has been shown to reduce the quality of the doctor–patient relationship (Margolius and Bodenheimer, 2010) and patient satisfaction (Fan *et al.*, 2005), which will consequently deplete attractiveness and reduce patient visits.

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

Feedback loop B4 portrays how the quality of care is affected by the length of consultation. As the number of patient visits increases, the length of consultation decreases, because doctors will reduce the time spent with an individual patient in order to manage their patient load. Evidence (Campbell *et al*., 2001a) suggests that as the length of consultation decreases, fewer of the needs of patients with chronic diseases can be addressed during a visit, which impacts the quality of care. In addition, integration of chronic care services among various providers and capability of care providers influence the quality of care (Howie *et al*., 1991, Kiran *et al*., 2015). As the quality of care increases, patient satisfaction, the attractiveness of venue and patient visits are expected to increase (which will, in turn, reduce the length of consultation). It must be noted that the dynamics in this sector is similar for all venues of care (GPs, polyclinics and SOCs).

General Practitioner Networks and Relationships

The GP networks and relationships sector (Figure 5) captures the dynamic interactions of three determinants of the quality of care for patients with chronic diseases seeking care at a GP clinic: (i) trust between public and private practitioners (Mur-Veeman *et al*., 2003), (ii) the fraction of GPs well trained to care for patients with complex chronic diseases (e.g. GPs with training in family medicine) (Jackson *et al*., 2010) and (iii) the fraction of GPs in a network (group practice) (Mehrotra *et al*., 2006). These factors are important within the Singapore context because it is generally believed that many GPs in Singapore are not sufficiently trained in chronic care provision. Moreover, the majority of GPs work in single practice with a little support system to provide care for individuals with chronic diseases. As a consequence, specialists do not have much confidence that GPs have the resources to manage complex patients, which then reduces their willingness to refer patients back to GPs, allowing these patients to accumulate in the SOCs.

Trust between GPs and SOCs is influenced by integration of care between GPs and SOCs (i.e. joint responsibility and coordination of care) and the perception specialists have of GPs' capabilities in providing chronic care. Integration of care is assumed to increase as a consequence of the trust between GPs and SOCs, while the perception specialists have of GPs' capabilities is influenced by the quality of chronic care provided by GPs. The fraction of GPs in a network (group practice) is influenced by the income differential between the group and single practice GPs and the capabilities of group practice relative to single practice (such as availability of nurses, facilities and equipment to support care provision). As the proportion of GPs in group practices rises, the possibility of further training to improve practice (such as training for registration in Family Medicine) increases because salaried GPs in a group practice will not face the loss of income and will not need to hire temporary physicians if they take time out to train.

Feedback loop R1 describes how trust between GPs and SOCs contributes to the quality of care. Improvement in trust between GPs and SOCs increases integration of care, which contributes to the quality of care. This, in turn, creates among specialists a positive perception of GPs' capability in providing chronic care, thus further reinforcing the trust between them. Feedback loop R2 depicts a simple relationship of trust building and integration of care. As trust between GPs and SOCs increases, integration of care between GPs and SOCs is expected to rise (Thorsen *et al*., 2012), as more patients are referred between these providers to encourage 'right-siting' of patients (the provision of care at the most efficient setting) (Gandhi *et al*., 2000, Manca *et al*., 2011), which further reinforces trust building. Feedback loop R3 depicts the dynamics of GP group practice development. Reinforcing loop R3 postulates that as the fraction of GPs in group practice increases, the attractiveness of a group practice (ability to expand the practice, favourable income differential and opportunity for further training) will increase, further increasing the number of GPs joining group practices. See Table 1 for the full list of the feedback loops in the chronic disease care delivery model.

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

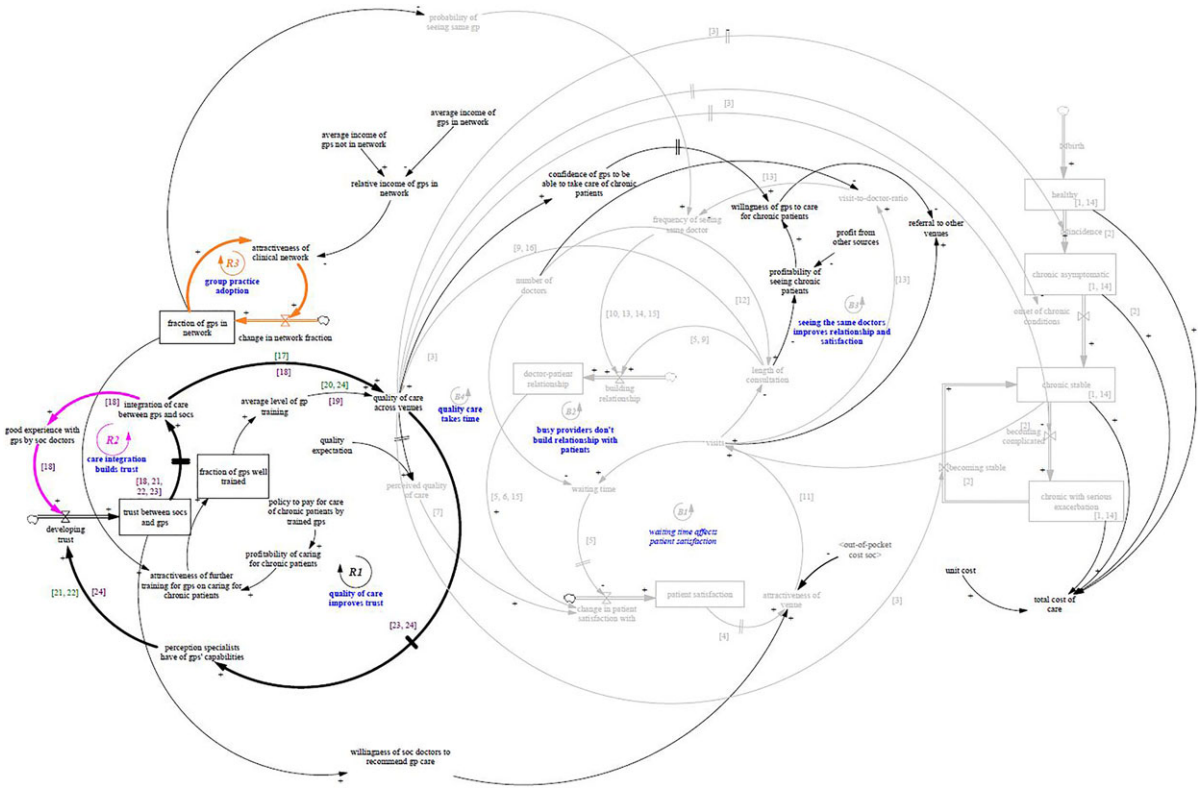

Figure 5 Adding general practitioner networks and relationships sector. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 1 Feedback loops

Loop	Variables
B1	Attractiveness of venue→ visits→ waiting time→ change in patient satisfaction→ patient satisfaction→ attractiveness of venue
B2	Length of consultation→ building relationship→ doctor–patient relationship→ change in patient satisfaction→ patient satisfaction→ attractiveness of venue→ visits→ length of consultation
B3	Frequency of seeing same doctor→ building of relationship→ doctor–patient relationship→ change in patient satisfaction→ patient satisfaction→ attractiveness of venue→ visits→ visits-to-doctor ratio→ frequency of seeing same doctor
B4	Visits→ length of consultation→ quality of care across venues→ perceived quality of care→ change in patient satisfaction→ patient satisfaction→ attractiveness of venue→ visits
R1	Trust between SOCs and GPs→ integration of care between SOCs and GPs→ quality of care across venues→ perception specialists have of GPs capabilities→ developing trust→ trust between SOCs and GPs
R2	Trust between SOCs and GPs→ integration of care between SOCs and GPs→ good experience with GPs and SOCs doctors→ developing trust→ trust between SOCs and GPs
R3	Fraction of GPs in network→ attractiveness of clinical networks→ change in network fraction→ fraction of GPs in network

GP, general practitioner; SOC, specialist outpatient clinic.

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

Suggested Policies

Extensive discussion with stakeholders led to the identification of five important areas of intervention to improve chronic disease care delivery in Singapore (Figure 6). The stakeholders articulated the need for targeted policies to (i) improve the capabilities of GPs to provide chronic disease care, (ii) to ensure care continuity for chronic disease patients, (iii) to increase the use of GP services for chronic disease care, (iv) to reduce the workload of polyclinic doctors to improve care and (v) to support GP group practice.

A policy that makes it mandatory for all new GPs in Singapore to receive additional training in family medicine before they are allowed to practice as GPs was suggested to increase the capabilities of GPs to provide adequate chronic care. Other policies such as patient empanelment and capitation/bundle payment was suggested to ensure continuity of care for chronic disease patients. It was argued that these policies—patient empanelment and capitation/bundle payment—have the potential to increase the use of GP services by chronic disease patients and ensure continuity of care, given the available capacity and capability of GPs. The stakeholders were of the opinion that policies that increase the attractiveness of GP services (i.e. extending subsidies to patients with chronic diseases seeking care with private GPs as is the case for patients seeking care at polyclinics) will indirectly reduce the workload of the polyclinics and improve patient experience. Lastly, the stakeholders

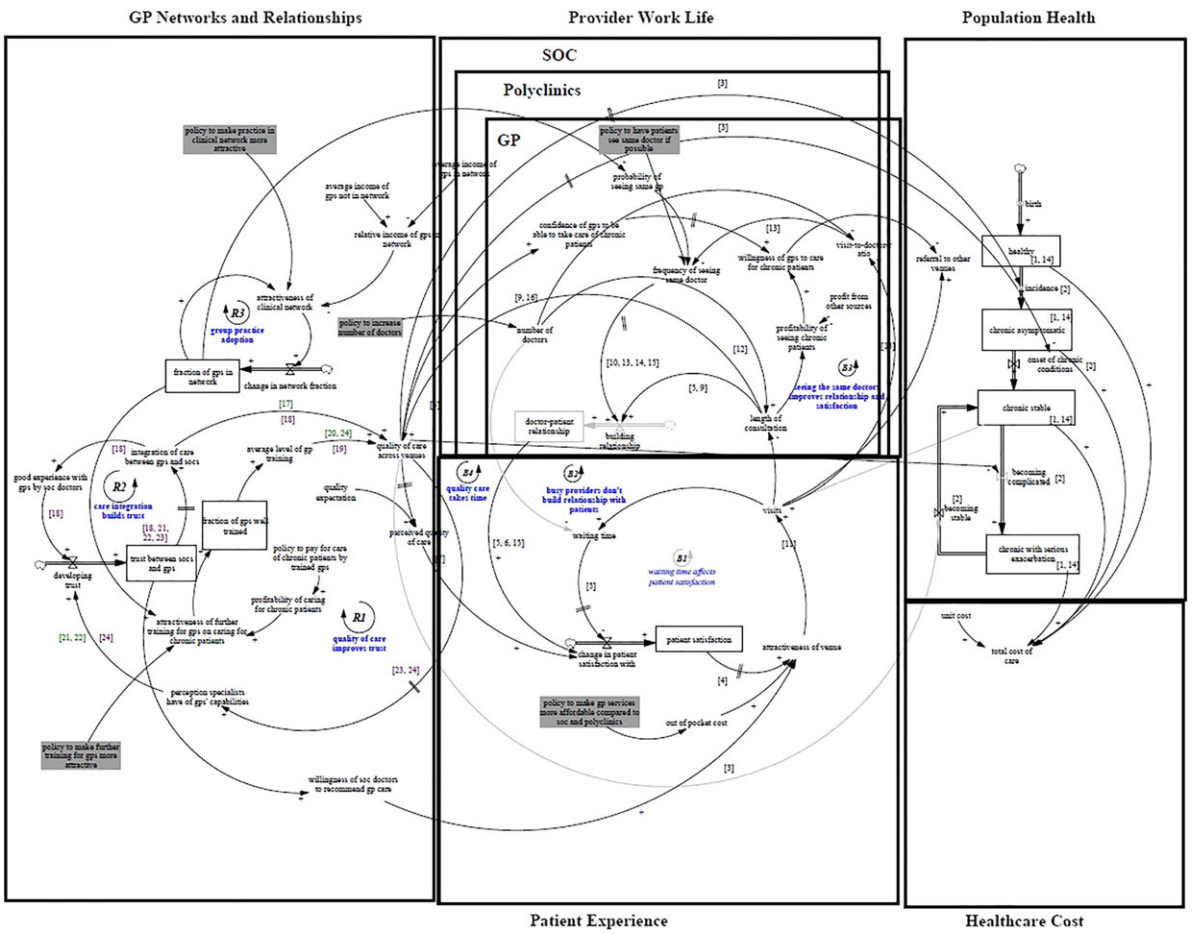

Figure 6 Adding suggested policies. [Colour figure can be viewed at wileyonlinelibrary.com]

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

suggested the need for the government to provide sustainable community-based services—such as digital diabetic retinopathy photography, diabetic foot screening, nurse counselling and education, diabetes services and laboratory services—to support GP group practice for chronic disease care.

DISCUSSION

This study describes a GMB exercise that aims to develop a deeper understanding of the dynamic complexity of chronic disease care delivery within a primary care setting in Singapore, leveraging on the insights of stakeholders with deeply personal and institutional knowledge. The qualitative system dynamics model developed in the GMB exercise helped to bring a feedback perspective to understanding the dynamic complexity of chronic disease care delivery. The feedback perspective helped in identifying the systemic issues within chronic disease care delivery, which has the potential to inform system-wide interventions and policies to improve health.

Insights generated and captured in the qualitative model are shown in Figure 5. Firstly, monetary incentives were found to have substantial influences on the uptake and provision of health services by both patients (out-of-pocket cost) and providers (price of visit). This insight is captured by the policy to make GP services more affordable. Most patients seeking chronic care in Singapore are price sensitive; a venue of care with lower out-of-pocket costs is deemed more attractive. Not only is this a consideration for a patient's current visit but also for follow-up visits or referral to specialty care in the future. Referrals to specialty care from a private GP is usually not subsidized. In addition, patients are sensitive to drug prices, which are subsidized in the public sector. This, together with the walk-in model of the primary care sector, has led many patients to seek episodic services (cough and cold) with private GPs and chronic care in the public polyclinics and SOCs. Thus, it is important to understand the types of services required by each segment of the population in order to provide adequate and quality care that is financially sustainable for the population.

Secondly, from the providers' perspective, some private GPs expressed concerns that many GPs lack confidence in treating patients with chronic diseases yet are discouraged from engaging in additional training as the opportunity costs of training can be high. This insight is illustrated in the model by the policy to make further training for GPs more attractive to increase their capability. Because many GPs work in solo practices, clinic operations would have to be temporarily suspended while they attend courses. Although stand-in doctors may be employed, they are usually not readily available and incur additional costs. Further, course fees are borne by the GPs themselves in the private sector, unlike public sectors where training may be sponsored. In addition, lucrative alternatives to providing care to medically complex patient, such as providing aesthetic services, are readily available. Hence, most private GPs are not incentivized to further develop their skills in chronic disease care.

Thirdly, insights from the discussion suggest that group practices are becoming attractive to some of the GPs. This finding is captured by the policy to make practice in clinical networks more attractive. Some private GPs have begun to collaborate to enhance their capacity and capability in managing chronic diseases. This allows for resource sharing such as nurses, equipment, and technical expertise and also encourages GPs to take up training courses. While this service model is promising in terms of generating positive health outcomes, its financial viability is yet to be demonstrated and thus has not gained the buy-in from most solo private GPs.

Lastly, the strength and relevance of each feedback loop and how they impact the care-seeking behavior of patients across care venues depends on variables such as patient satisfaction, perceived quality of care, doctor–patient relationship and out-of-pocket costs. Identifying these variables and their hypothesized causal relationships is an important aspect that this feedback perspective highlights. As such, the qualitative model when translated into a quantitative simulation model will allow for the investigation of the conditions under which the policies to

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

improve the care of individuals with chronic diseases are likely to succeed or fail. Quantifying the model and estimating it empirically would allow for assessing the relative strengths of different mechanisms and factors that influence patient preference of care venue and testing alternative policy options. Such a model could play a significant role in informing policy on investment in care services and regulatory changes.

CONCLUSION

Enhancing chronic care in Singapore will require enhancing both the capacity and capability of the primary care sector. While the private sector has the potential capacity to be mobilized and has expressed interest in becoming part of the solution, the financial viability of delivering such care is still a primary concern. A major potential policy option is to empanel patients in high-risk segments under contracts (e.g. similar to commissioning done in the UK NHS). This scheme requires a high level of trust and a good working relationship between the public and private sectors. It is evident from this exercise that success will depend on enhancing trust between private GPs and the public SOCs. In addition, there must be an enhancement of communication, for example, via shared electronic medical records.

As a next step, the research team is developing a detailed proposal for a quantitative representation of the qualitative model. After which, the best estimates of the inputs will be used to populate the model and simulate for generating insights.

ACKNOWLEDGEMENTS

J. A. and D. M. conceived of the study, participated in its design and supervised the model development. J. A. and V. K. drafted the manuscript. J. A., D. M., V. K. and L. S. revised the manuscript, provided conceptual support and critical evaluation. All authors read and approved the final manuscript. The production of this manuscript was funded by the Singapore Ministry of Health's National Medical Research Council under its STaR Award Grant (grant number NMRC | STaR | 0005 | 2009) as part of the project 'Establishing a Practical and Theoretical Foundation for Comprehensive and Integrated Community, Policy and Academic Efforts to Improve Dementia Care in Singapore'.

COMPETING INTERESTS

The authors declare that they have no competing interests.

REFERENCES

Allender S, Owen B, Kuhlberg J *et al*. 2015. A community based systems diagram of obesity causes. *PloS One* **10**(7): e0129683.

Alrubaiee L, Alkaa'ida F. 2011. The mediating effect of patient satisfaction in the patients' perceptions of healthcare quality—patient trust relationship. *International Journal of Marketing Studies* **3**(1): 103.

Anantharaman V. 2008. Impact of health care system interventions on emergency department utilization and overcrowding in Singapore. *International Journal of Emergency Medicine* **1**(1): 11–20.

Anderson RT, Camacho FT, Balkrishnan R. 2007. Willing to wait?: the influence of patient wait time on satisfaction with primary care. *BMC Health Services Research* **7**(1): 31–31.

Campbell JL, Ramsay J, Green J. 2001a. Practice size: impact on consultation length, workload, and patient assessment of care. *British Journal of General Practice* **51**(469): 644–650.

Campbell SM, Hann M, Hacker J *et al*. 2001b. Identifying predictors of high quality care in english general practice: observational study. *BMJ: British Medical Journal* **323**(7316): 784–787.

Denton FT, Spencer BG. 2015. Modelling the age dynamics of chronic health conditions: life-table-consistent transition probabilities and their application. *Canadian Journal on Aging/La Revue Canadienne du Vieillissement* **34**(2): 176–193.

Derose SF, Petitti DB. 2003. Measuring quality of care and performance from a population health care perspective. *Annual Review of Public Health* **24**: 363.

Dettmer HW. 1997. *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement*. ASQC Quality Press: Milwaukee, Wis.

Ellis B. 2010. Complexity in practice: understanding primary care as a complex adaptive system. *Informatics in Primary Care* **18**(2): 135.

Fan VS, Burman M, McDonell MB, Fihn SD. 2005. Continuity of care and other determinants of patient

satisfaction with primary care. *Journal of General Internal Medicine* **20**(3): 226–233.
Forrester JW. 1961. *Industrial Dynamics*. M.I.T. Press: Cambridge, Mass.
Gandhi TK, Sittig DF, Franklin M, Sussman AJ, Fairchild DG, Bates DW. 2000. Communication breakdown in the outpatient referral process. *Journal of General Internal Medicine* **15**(9): 626–631.
Himmel W, Dieterich A, Kochen MM. 2000. Will german patients accept their family physician as a gatekeeper? *Journal of General Internal Medicine* **15**(7): 496–502.
Hirsch GB, Homer J. 2004. Modeling the dynamics of health care services for improved chronic illness management. 22nd International Conference of System Dynamics Society, Oxford, England.
Hjortdahl P, Lærum E. 1992. Continuity of care in general practice: effect on patient satisfaction. *BMJ: British Medical Journal* **304**(6837): 1287–1290.
Homa L, Rose J, Hovmand PS *et al*. 2015. A participatory model of the paradox of primary care. *Annals of Family Medicine* **13**(5): 456.
Homer JB, Hirsch GB. 2006. System dynamics modeling for public health: background and opportunities. *American Journal of Public Health* **96**(3): 452–458.
Homer JB, Hirsch GB, Milstein B. 2007. Chronic illness in a complex health economy: the perils and promises of downstream and upstream reforms. *System Dynamics Review* **23**(2/3): 313–343.
Hovmand PS. 2014. *Community Based System Dynamics*. Springer: New York.
Howie JG, Porter AM, Heaney DJ, Hopton JL. 1991. Long to short consultation ratio: a proxy measure of quality of care for general practice. *The British journal of general practice : the journal of the Royal College of General Practitioners* **41**(343): 48–54.
Jackson C, Tsai J, Brown C, Askew D, Russell A. 2010. GPs with special interests: impacting on complex diabetes care. *Australian Family Physician* **39**(12): 972–974.
Kang SH, Leong CH. 2012. *Singapore Perspectives 2012: Singapore Inclusive: Bridging Divides*. World Scientific Publishing Company: Singapore.
Kiran T, Kopp A, Moineddin R, Glazier RH. 2015. Longitudinal evaluation of physician payment reform and team-based care for chronic disease management and prevention. *CMAJ : Canadian Medical Association journal = journal de l'Association medicale canadienne* **187**(17): E494.
Kulu-Glasgow I, Delnoij D, de Bakker D. 1998. Self-referral in a gatekeeping system: patients' reasons for skipping the general-practitioner. *Health Policy* **45**(3): 221–238.
Lam PM. 2013. *GPC (Health) Report On Improving Healthcare Affordability For Singaporeans*. Ministry of Health: Singapore.
Lam PM. 2014. Bed crunch. Retrieved 23 March 2016, from https://www.moh.gov.sg/content/moh_web/home/pressRoom/Parliamentary_QA/2014/bed-crunch.html.
Loyo HK, Batcher C, Wile K, Huang P, Orenstein D, Milstein B. 2013. From model to action: using a system dynamics model of chronic disease risks to align community action. *Health Promotion Practice* **14**(1): 53–61.
Lynn J, Straube BM, Bell KM, Jencks SF, Kambic RT. 2007. Using population segmentation to provide better health care for all: the "bridges to health" model. *The Milbank Quarterly* **85**(2): 185–208.
Manca DP, Breault L, Wishart P. 2011. A tale of two cultures specialists and generalists sharing the load. *Canadian Family Physician* **57**(5): 576–584.
Mandel D, Zimlichman E, Wartenfeld R, Vinker S, Mimouni FB, Kreiss Y. 2003. Primary care clinic size and patient satisfaction in a military setting. *American Journal of Medical Quality* **18**(6): 251–255.
Margolius D, Bodenheimer T. 2010. Transforming primary care: from past practice to the practice of the future. *Health affairs (Project Hope)* **29**(5): 779–784.
Mehrotra A, Epstein AM, Rosenthal MB. 2006. Do integrated medical groups provide higher-quality medical care than individual practice associations? *Annals of Internal Medicine* **145**(11): 826.
Ministry of Health. 2001. Waiting times in specialist outpatient clinics of restructured hospitals and specialty centres. Retrieved 23 March 2016, from https://www.moh.gov.sg/content/moh_web/home/pressRoom/pressRoomItemRelease/2001/waiting_times_in_specialist_outpatient_clinics_of_restructured_hospitals_and_specialty_centres.html.
Ministry of Health. 2012. MOH 2012 committee of supply speech healthcare 2020: improving accessibility, quality and affordability for tomorrow's challenges (part 1 of 2). Retrieved 22 March 2016, from http://www.moh.gov.sg/content/moh_web/home/pressRoom/speeches_d/2012/moh_2012_committeeofsupplyspeechhealthcare2020improving-accessibi.html
Ministry of Health. 2015a. Disease burden. Retrieved 22 Feb 2016, from https://www.moh.gov.sg/content/moh_web/home/statistics/Health_Facts_Singapore/Disease_Burden.html.
Ministry of Health. 2015b. Primary healthcare services. Retrieved 16 Feb 2016, from https://www.moh.gov.sg/content/moh_web/home/our_healthcare_system/Healthcare_Services/Primary_Care.html.
Ministry of Health. (2016a). Beds occupancy rate (BOR). Retrieved 23 March 2016, from https://www.moh.gov.sg/content/moh_web/home/statistics/healthcare_institutionstatistics/Beds_Occupancy_Rate_BOR.html.
Ministry of Health. 2016b. Waiting time for admission to ward. Retrieved 23 March 2016, from https://www.moh.gov.sg/content/moh_web/home/statistics/healthcare_institutionstatistics/Waiting_Time_for_Admission_to_Ward.html.

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

Murray M. 2007. Panel size: how many patients can one doctor manage? *Family Practice Management* **14**(4): 44.
Mur-Veeman I, Hardy B, Steenbergen M, Wistow G. 2003. Development of integrated care in England and the Netherlands: managing across public-private boundaries. *Health policy (Amsterdam, Netherlands)* **65**(3): 227–241.
National Population and Talent Division. 2012. Issues paper 2012—our demographic challenges and what these means to us. Retrieved 23 March 2016, from http://population.sg/key-challenges/#.VvHu8NJ96Uk.
Noreen EW, Smith D, Mackey JT, Price W, Research IMAF f A. 1995. *The Theory of Constraints and Its Implications for Management Accounting*. North River Press: Great Barrington, MA.
OECD. 2016. Health care quality indicators: primary care. Retrieved 23 March 2016, from http://stats.oecd.org/.
Richardson GP, Vennix JAM, Andersen DF, Rouwette EAJA. 2007. Group model building: problem structuring, policy simulation and decision support. *Journal of the Operational Research Society* **58**(5): 691–694.
Schoenenberger LK, Bayer S, Ansah JP *et al*. 2016. Emergency department crowding in Singapore: insights from a systems thinking approach. *SAGE Open Medicine* **4**.
Scott RJ, Cavana RY, Cameron D. 2016. Recent evidence on the effectiveness of group model building. *European Journal of Operational Research* **249**(3): 908–918.
Senge PM. 1990. *The Fifth Discipline: The Art and Practice of the Learning Organization*. Doubleday/Currency: New York.
Singapore Department of Statistics. 2015. Population trends 2015.
Singapore Department of Statistics. 2016. Latest data. Retrieved 23 March 2016, from http://www.singstat.gov.sg/statistics/latest-data#15.
Siokou C, Morgan R, Shiell A. 2014. Group model building: a participatory approach to understanding and acting on systems. *Public Health Research and Practice* **25**(1): 1–4.
Sloan FA, Kasper H. 2008. *Incentives and Choice in Health Care*. MIT Press: Cambridge, MA.
Sng QS. 2010. Primary care survey 2010 profile of primary care patients, Ministry of Health Singapore.
Sterman J. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill: Boston.
Sterman JD. 2001. System dynamics modeling: tools for learning in a complex world. *California Management Review* **43**(4): 8–25.
Thorsen O, Hartveit M, Baerheim A. 2012. General practitioners' reflections on referring: an asymmetric or non-dialogical process? *Scandinavian Journal of Primary Health Care* **30**(4): 241–246.
Vennix JAM. 1996. *Group Model Building: Facilitating Team Learning Using System Dynamics*. John Wiley: New York;Chichester, England.
Vennix JAM, Gubbels JW. 1992. Knowledge elicitation in conceptual model building: a case study in modeling a regional Dutch health care system. *European Journal of Operational Research* **59**(1): 85–101.
Wenger E. 1998. *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press: Cambridge, U.K;New York, N.Y.
Williams S, Weinman J, Dale J. 1998. Doctor-patient communication and patient satisfaction: a review. *Family Practice* **15**(5): 480–492.
World Health Organization. 2002. *Innovative Care for Chronic Conditions: Building Blocks for Action*. World Health Organization: Geneva.
Zastowny TR, Roghmann KJ, Cafferata GL. 1989. Patient Satisfaction and the use of health services: explorations in causality. *Medical Care* **27**(7): 705–723.

Syst. Res **35**, 759–775 (2018)
DOI: 10.1002/sres.2517

APPENDIX

Table A1 Model references

(1) Lynn J, Straube BM, Bell KM, Jencks SF, Kambic RT (2007) Using Population Segmentation to Provide Better Health Care for All: The "Bridges to Health" Model. The Milbank Quarterly 85 (2):185–208. doi:10.1111/j.1468-0009.2007.00483.x
(2) Denton FT, Spencer BG (2015) Modelling the Age Dynamics of Chronic Health Conditions: Life-Table-Consistent Transition Probabilities and their Application. Canadian Journal on Aging/La Revue Canadienne du Vieillissement 34 (2):176–193. doi:10.1017/S071498081500001X
(3) Derose SF, Petitti DB (2003) Measuring quality of care and performance from a population health care perspective. Annual review of public health 24:363
(4) Himmel W, Dieterich A, Kochen MM (2000) Will german patients accept their family physician as a gatekeeper? Journal of General Internal Medicine 15 (7):496–502. doi:10.1046/j.1525-1497.2000.10016.x
(5) Anderson RT, Camacho FT, Balkrishnan R (2007) Willing to wait?: the influence of patient wait time on satisfaction with primary care. BMC health services research 7 (1):31–31. doi:10.1186/1472-6963-7-31
(6) Williams S, Weinman J, Dale J (1998) Doctor-patient communication and patient satisfaction: a review. Family practice 15 (5):480–492. doi:10.1093/fampra/15.5.480
(7) Alrubaiee L, Alkaa'ida F (2011) The Mediating Effect of Patient Satisfaction in the Patients' Perceptions of Healthcare Quality – Patient Trust Relationship. International Journal of Marketing Studies 3 (1):103. doi:10.5539/ijms.v3n1p103
(8) Murray M (2007) Panel size: how many patients can one doctor manage? Fam Pract Manag 14 (4):44
(9) Howie JG, Porter AM, Heaney DJ, Hopton JL (1991) Long to short consultation ratio: a proxy measure of quality of care for general practice. The British journal of general practice: the journal of the Royal College of General Practitioners 41 (343):48–54
(10) Hjortdahl P, Lærum E (1992) Continuity Of Care In General Practice: Effect On Patient Satisfaction. BMJ: British Medical Journal 304 (6837):1287–1290
(11) Zastowny TR, Roghmann KJ, Cafferata GL (1989) Patient Satisfaction and the Use of Health Services: Explorations in Causality. Medical Care 27 (7):705–723
(12) Campbell JL, Ramsay J, Green J (2001) Practice size: impact on consultation length, workload, and patient assessment of care. British Journal of General Practice 51 (469):644–650
(13) Mandel D, Zimlichman E, Wartenfeld R, Vinker S, Mimouni FB, Kreiss Y (2003) Primary Care Clinic Size and Patient Satisfaction in a Military Setting. American Journal of Medical Quality 18 (6):251–255. doi:10.1177/106286060301800605
(14) Margolius D, Bodenheimer T (2010) Transforming primary care: from past practice to the practice of the future. Health affairs (Project Hope) 29 (5):779–784. doi:10.1377/hlthaff.2010.0045
(15) Fan VS, Burman M, McDonell MB, Fihn SD (2005) Continuity of care and other determinants of patient satisfaction with primary care. Journal of General Internal Medicine 20 (3):226–233. doi:10.1111/j.1525-1497.2005.40135.x
(16) Campbell SM, Hann M, Hacker J, Burns C, Oliver D, Thapar A, Mead N, Safran DG, Roland MO (2001) Identifying Predictors Of High Quality Care In English General Practice: Observational Study. BMJ: British Medical Journal 323 (7316):784–787. doi:10.1136/bmj.323.7316.784
(17) Kiran T, Kopp A, Moineddin R, Glazier RH (2015) Longitudinal evaluation of physician payment reform and team-based care for chronic disease management and prevention. CMAJ: Canadian Medical Association journal = journal de l'Association medicale canadienne 187 (17):E494. doi:10.1503/cmaj.150579
(18) Mur-Veeman I, Hardy B, Steenbergen M, Wistow G (2003) Development of integrated care in England and the Netherlands: managing across public-private boundaries. Health policy (Amsterdam, Netherlands) 65 (3):227–241. doi:10.1016/S0168-8510(02)00215-4
(19) Jackson C, Tsai J, Brown C, Askew D, Russell A (2010) GPs with Special Interests: Impacting on Complex Diabetes Care. Australian Family Physician 39 (12):972–974
(20) Mehrotra A, Epstein AM, Rosenthal MB (2006) Do Integrated Medical Groups Provide Higher-Quality Medical Care than Individual Practice Associations? Annals of Internal Medicine 145 (11):826
(21) Thorsen O, Hartveit M, Baerheim A (2012) General practitioners' reflections on referring: An asymmetric or non-dialogical process? Scandinavian Journal of Primary Health Care 30 (4):241–246. doi:10.3109/02813432.2012.711190

(*Continues*)

(22)Gandhi TK, Sittig DF, Franklin M, Sussman AJ, Fairchild DG, Bates DW (2000) Communication breakdown in the outpatient referral process. Journal of General Internal Medicine 15 (9):626–631. doi:10.1046/j.1525-1497.2000.91119.x
(23)Manca DP, Breault L, Wishart P (2011) A tale of two cultures Specialists and generalists sharing the load. Canadian Family Physician 57 (5):576–584
(24)Sampson R, Barbour R, Wilson P (2016) The relationship between GPs and hospital consultants and the implications for patient care: a qualitative study. BMC family practice 17:45. doi:10.1186/s12875-016-0442-y

Syst. Res **35,** 759–775 (2018)
DOI: 10.1002/sres.2517