

# Emergency department crowding in Singapore: Insights from a systems thinking approach

SAGE Open Medicine  
Volume 4: 1–10  
© The Author(s) 2016  
Reprints and permissions:  
sagepub.co.uk/journalsPermissions.nav  
DOI: 10.1177/2050312116671953  
smo.sagepub.com  


Lukas K Schoenenberger<sup>1</sup>, Steffen Bayer<sup>2</sup>, John P Ansa<sup>2</sup>,  
David B Matchar<sup>2,3</sup>, Rajagopal L Mohanavalli<sup>4</sup>,  
Sean SW Lam<sup>4</sup> and Marcus EH Ong<sup>2,5</sup>

## Abstract

**Objectives:** Emergency Department crowding is a serious and international health care problem that seems to be resistant to most well intended but often reductionist policy approaches. In this study, we examine Emergency Department crowding in Singapore from a systems thinking perspective using causal loop diagramming to visualize the systemic structure underlying this complex phenomenon. Furthermore, we evaluate the relative impact of three different policies in reducing Emergency Department crowding in Singapore: introduction of geriatric emergency medicine, expansion of emergency medicine training, and implementation of enhanced primary care.

**Methods:** The construction of the qualitative causal loop diagram is based on consultations with Emergency Department experts, direct observation, and a thorough literature review. For the purpose of policy analysis, a novel approach, the path analysis, is applied.

**Results:** The path analysis revealed that both the introduction of geriatric emergency medicine and the expansion of emergency medicine training may be associated with undesirable consequences contributing to Emergency Department crowding. In contrast, enhancing primary care was found to be germane in reducing Emergency Department crowding; in addition, it has apparently no negative side effects, considering the boundary of the model created.

**Conclusion:** Causal loop diagramming was a powerful tool for eliciting the systemic structure of Emergency Department crowding in Singapore. Additionally, the developed model was valuable in testing different policy options.

## Keywords

Critical care/emergency medicine, Emergency Department crowding, systems thinking, causal loop diagramming, path analysis, policy analysis, modelling

Date received: 2 March 2016; accepted: 22 August 2016

## Introduction

Emergency Department (ED) crowding has become a severe and growing problem threatening public health worldwide.<sup>1</sup> In 2006, the American College of Emergency Physicians defined ED crowding as follows: ‘Crowding occurs when the identified need for emergency services exceeds available resources for patient care in the emergency department, hospital, or both’. Thus, ED crowding is a consequence of an imbalance between demand and supply of emergency medicine services within the ED and limited hospital capacity.<sup>2,3</sup> Constraints in hospital capacity lead to ‘access block’ where ED patients cannot be admitted to the hospital wards and ‘board’ or ‘lodge’ inside the ED.

<sup>1</sup>Faculty of Business and Economics, University of Basel, Basel, Switzerland

<sup>2</sup>Program in Health Services and Systems Research, Duke-NUS Graduate Medical School, Singapore

<sup>3</sup>Department of Medicine, Duke University Medical Center, Durham, NC, USA

<sup>4</sup>Health Services Research and Biostatistics Unit, Division of Research, Singapore General Hospital, Singapore

<sup>5</sup>Department of Emergency Medicine, Singapore General Hospital, Singapore

### Corresponding author:

Lukas Schoenenberger, Faculty of Business and Economics, University of Basel, Peter Merian-Weg 6, 4052 Basel, Switzerland.  
Email: lukas.schoenenberger@unibas.ch

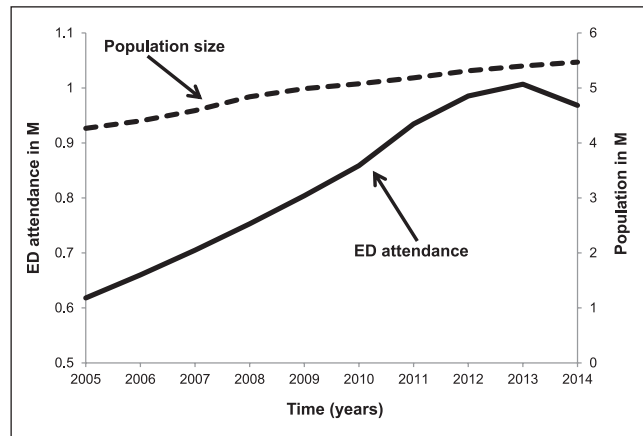


Most importantly, crowding can compromise patients' health outcomes by delaying care and causing poor quality of care.<sup>3</sup> ED crowding is equally important to both policymakers and researchers aiming to better understand and suggest appropriate and sustainable solutions for this phenomenon. ED crowding is one of the dominant threads in the emergency medicine literature and has gained the attention of researchers globally.<sup>4</sup>

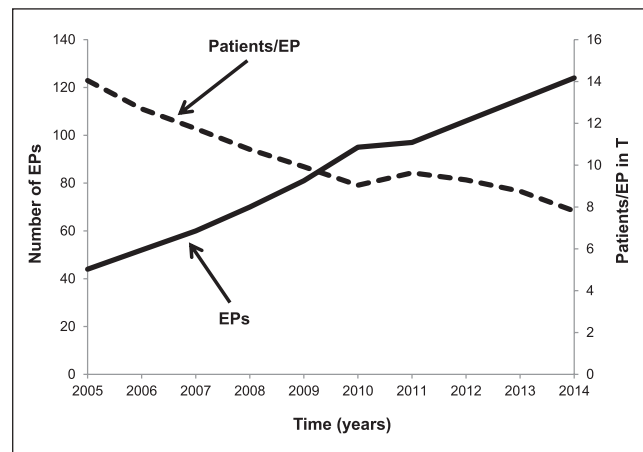
Between 1998 and 2008, EDs in the United States have experienced an approximate growth in patient visits of 30%, that is, from 94.8 million visits in 1998 to 123 million visits in 2008, while a third of urban area EDs were shut down,<sup>5</sup> reminding us of the Institute of Medicine's assessment in 2006 that US EDs are operating near or at the very 'breaking point'.<sup>6</sup> In 2004, after having experienced years of heavy ED crowding, the United Kingdom implemented the '4-hour rule' demanding that 98% of all ED patients must be seen and discharged or admitted within 4 h of their arrival.<sup>7</sup> The rule was highly effective in reducing ED patients' length of stay (LOS) but, at the same time, generated unintended side effects. Most notably, the emergency physicians (EPs) have tended to prioritize attainment of the 4-h target over thorough evaluation. As a consequence, more patients are admitted to the hospital shifting the workload from the ED to downstream wards.<sup>1</sup> The UK experience illustrates that because ED crowding is a reflection of larger supply and demand mismatches in the health care system, the problem cannot be solved by policies which examine the ED in isolation.<sup>2</sup>

In 2014, the total population of Singapore amounts to 5.47 million with an average annual growth rate of 1.3%.<sup>8</sup> In comparison, total ED attendance has grown at a disproportionately higher rate, that is, roughly 6.8% per year between 2005 and 2011.<sup>9</sup> Despite the slowing down of ED attendance growth rates between 2011 and 2014, total ED attendance hit the 1 million mark in 2013.<sup>10</sup> The number of EPs has increased as well with an average annual growth rate of 13.4% from 2005 to 2014.<sup>9</sup> Notwithstanding the rise in EPs in past years, their workload has remained very high, for example, each EP has seen on average 7809 patients in 2014.<sup>9,10</sup> Figure 1 illustrates the evolution of both total ED attendance and population size in Singapore for the period from 2005 to 2014. For the same time period, Figure 2 shows the development of both number of EPs and the average amount of patients an EP has to handle in Singapore per year.

The problem of (over)crowded EDs has been reported nationwide, linked to long waiting times and high hospital bed occupancy.<sup>9</sup> Furthermore, in absolute numbers, Singapore has still too few EPs for an efficient and effective treatment of all patients presenting at the EDs. Previous studies have suggested that the optimal ED throughput is about 2–2.8 patients per EP per hour.<sup>11</sup> In Singapore, however, this rate lies between 6.4 and 8.5 patients per EP per hour depending on the mode of calculation.<sup>9</sup> This suggests that the current state of emergency medical care in Singapore



**Figure 1.** Evolution of total population and ED attendance in Singapore from 2005 to 2011.

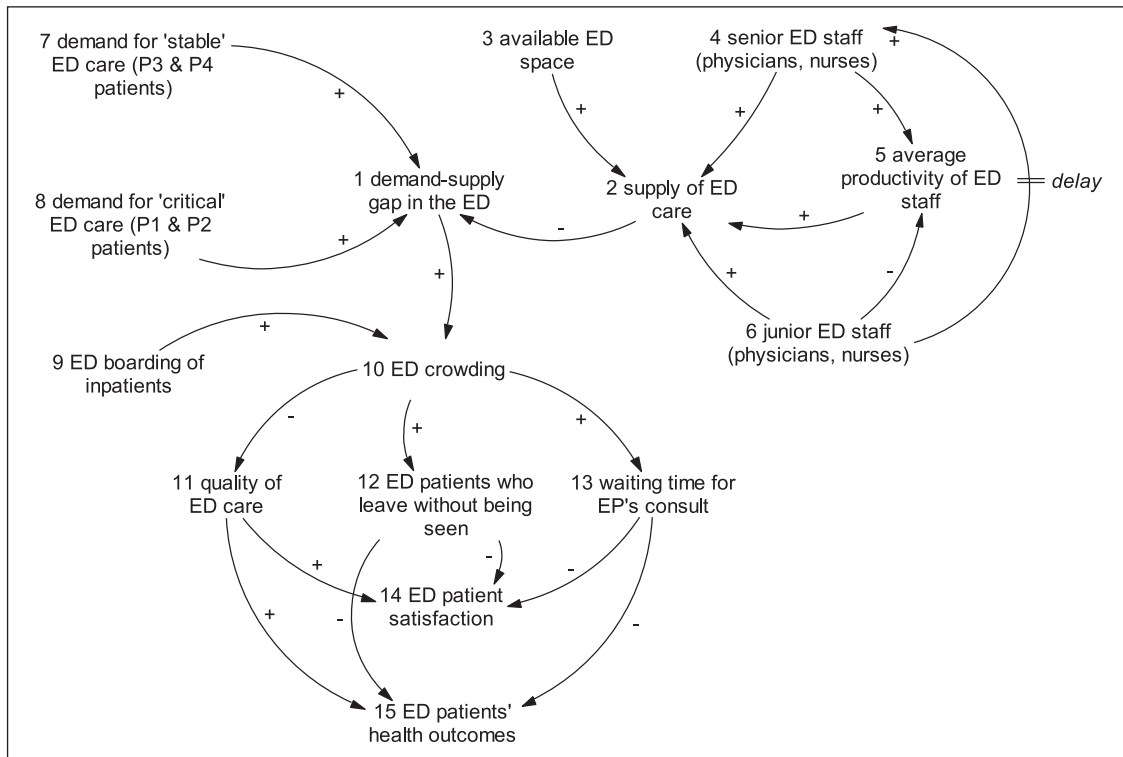


**Figure 2.** Evolution of EPs and patients/EP in Singapore from 2005 to 2011.

may not be sustainable and has implications on patients' and ED staff health.

Many studies have argued that ED crowding is a complex systems problem that cannot be effectively tackled by reductionist or piecemeal approaches.<sup>2,4,12</sup> A recent systematic literature review of ED crowding concludes that 'when considered as a whole, the body of literature demonstrates that ED crowding is a local manifestation of a systemic disease'.<sup>3</sup> Therefore, in this article, we explore ED crowding in Singapore using a *systems thinking* approach.

Systems thinking is a distinct 'way of thinking' that appreciates the very nature of complex systems – such as health systems – as dynamic, history dependent, and governed by feedbacks.<sup>13,14</sup> Recently, systems thinking has gained traction in health research as two special issues in *Health Policy and Planning* (2012) and *Health Research Policy and Systems* (2014) on the topic were published. Scholars in health systems research even argue that a paradigm shift is needed away from 'linear, reductionist



**Figure 3.** Core model structure of ED crowding.

approaches to dynamic and holistic approaches that appreciate the multifaceted and interconnected relationships among health system components [...].<sup>13</sup>

In this study, our aim is to elicit the systemic structure reflecting the drivers and consequences of ED crowding for both patients and ED staff, in order to gain a better understanding of this phenomenon both locally, in Singapore, and internationally. In addition, based on the systemic structure, we test the relative impact of three different policies in reducing ED crowding that are currently discussed by policy-makers in Singapore – these are introduction of geriatric emergency medicine in EDs, expansion of ED staff training, and implementation of enhanced primary care in Singapore.

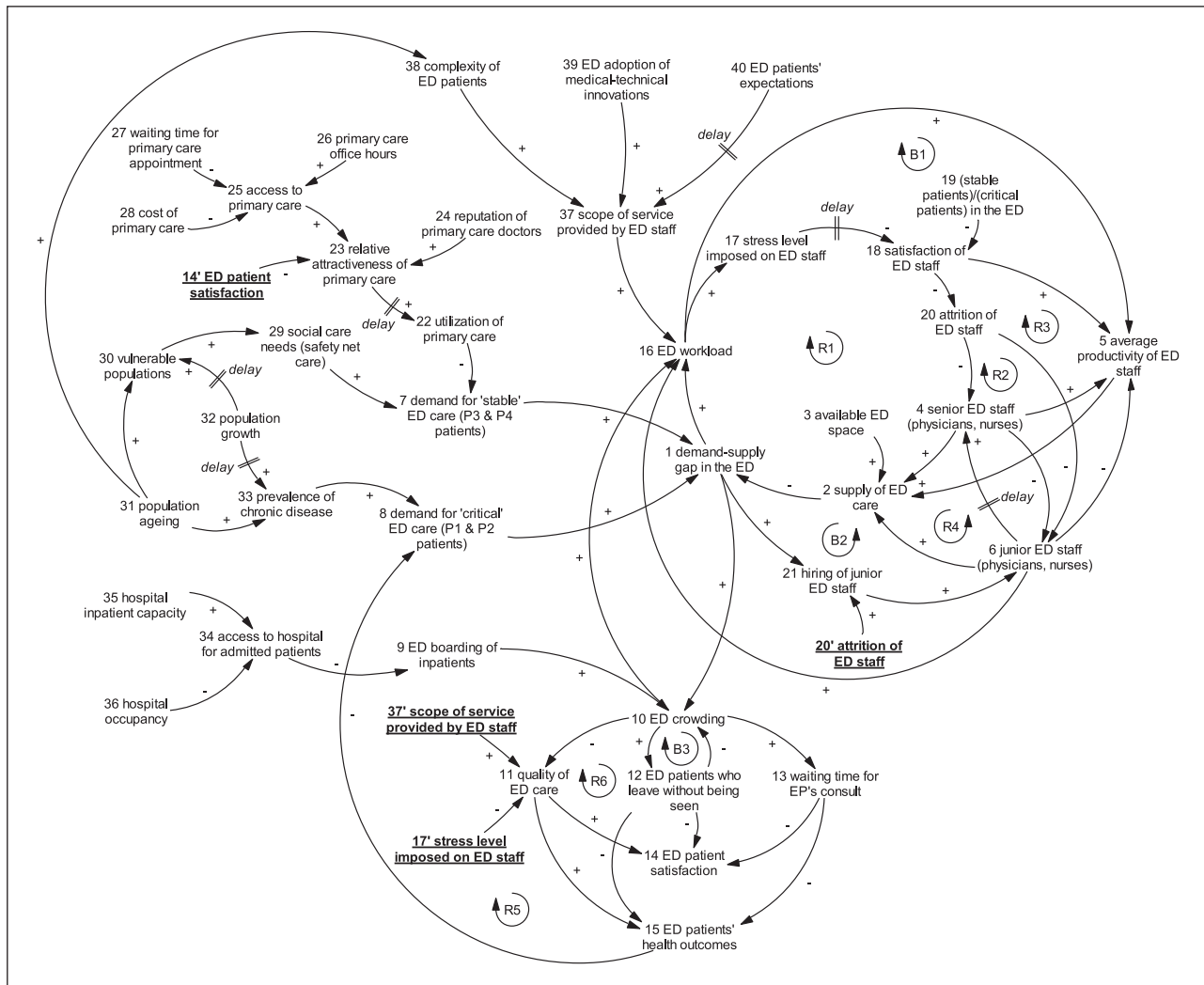
## Methods

### Causal loop diagramming

Within the realm of systems thinking, many theories, methods, and tools exist.<sup>15</sup> In this article, we focus on ‘causal loop diagramming’ to visualize the systemic structure underlying ED crowding in Singapore.<sup>16</sup> In this study, we developed a causal loop diagram (CLD) to articulate our understanding of the complex relationships, dynamics, and interconnectedness between interacting variables that are affecting or are affected by ED crowding.<sup>17</sup> The resulting CLD is a conceptual (qualitative) model. Within our CLD depicted in Figures 3 (core model) (To be precise, the core model depicted in Figure 3 is

a causal model rather than a CLD because it has no feedback loops.) and 4 (complete model), an arrow indicates the direction of a causal relationship, while the pluses (+) and minuses (–) on the arrows denote polarity of relationships. A positive relationship (arrow with a ‘+’) implies that, all else being equal, an increase in the cause variable causes an increase in the effect variable *above what it would otherwise have been* or vice versa, so the change is in the same direction. A negative relationship (arrow with a ‘–’) implies that, all else being equal, an increase in the cause variable causes a decrease in the effect variable *below what it would otherwise have been* or vice versa, so the change is in the opposite direction. Additionally, a set of two parallel lines across an arrow mean that there is a significant time lag between cause and effect variable.<sup>16</sup>

Our CLD is a causal theory explaining the behaviour of ED crowding by focusing on feedback loops. A feedback loop occurs when a variable, through a series of other variables, is linked back to itself.<sup>17</sup> Feedback loops can be either positive or reinforcing, where A creates more B which in turn creates more A, such as the vicious cycle of undernutrition and infection; or they can be balancing or negative, where a positive change in one variable leads to a push back in the opposite direction, as it is the case with body temperature and sweating.<sup>15</sup> Within the CLD in Figure 4, important reinforcing and balancing feedback loops are denoted by the capitalized letters ‘B’ (balancing) and ‘R’ (reinforcing).



**Figure 4.** Expanded model structure of ED crowding.

### Causal inference: the path analysis

Causal inference in a CLD deals with determining the impact of a given cause variable on a given effect variable.<sup>18</sup> For example, this could be the impact of changing a policy variable (e.g. improving access to primary care) on an outcome variable (e.g. ED crowding) in a CLD. For this purpose, a 'path analysis' is performed, where a path is defined as a sequence of distinct variables that connect the cause to the effect variable in a CLD.<sup>19</sup>

The path analysis considers all paths from a given cause variable to a given effect variable and compares them in terms of their relative impact on the effect variable and the relative magnitude of their delay. In this context, we use the polarity of a path, that is, the total polarity of a link sequence, to determine a path's relative impact on an effect variable. The polarity of a path is simply calculated by multiplying a path's individual link polarities.<sup>20–22</sup> Analogously to the polarity of a relationship, a positive path means that if the

cause variable, that is, the first variable on a path, increases, the effect variable, that is, the last variable on a path, increases *above what it would otherwise have been* or vice versa, so the change is in the same direction. A negative path implies that if the cause variable at the head of a path increases, the effect variable at the tail of a path decreases *below what it would otherwise have been* or vice versa, so the change is in the opposite direction.

The relative delay of paths is used to distinguish between short-term and long-term effects of policies. For this reason, we need to differentiate between causal relationships, that is, links, having a significant time delay and non-delayed ones. We capture this information using the qualitative coding procedure described in an article in the *System Dynamics Review* where '1' indicates no significant time delay between variable pairs and '4' if prominent delays exist.<sup>22</sup> The relative delay of a path is then calculated by adding up its individual link delays. In this study, we defined paths having a relative delay of less than 10 as short-term policy effects. In contrast,

**Table 1.** Calculation of relative impact, that is, path polarity, and relative delay of two different causal paths.

Causal path	Relative impact	Relative delay
	+	3
	-	6

paths having a relative delay of 10 or more are long-term policy effects.

Table 1 illustrates the calculation of both the relative impact and the relative delay of two causal paths. The first path implies that *ED adoption of medical-technical innovations*, that is, the cause or policy variable, has a positive relative impact on the *stress level imposed on ED staff*, that is, the effect or outcome variable. Consequently, if the ED adopts more medical-technical innovations, this may increase the stress level of ED employees *above what it would otherwise have been* or vice versa. The relative delay of this path is three because it contains non-delayed causal relationships only. In contrast, the second path means that *access to primary care* has a negative relative impact on the *demand for 'stable' ED care*. Thus, improving primary care access may decrease 'stable' ED care demand *below what it would otherwise have been* or vice versa. The relative delay of this path is six because it contains one significantly delayed relationship and two non-delayed ones. Both the identification of these paths and the measurement of their relative impact and delay values are fully automated based on an algorithmic approach.<sup>22</sup>

The path analysis can be used as a preliminary instrument to evaluate different policies because it helps policy-makers to recognize both potential intended *and* unintended consequences of their policy proposals. An intended consequence of a policy means that the outcome variable (e.g. ED crowding) is influenced in a desirable way (e.g. ED crowding is lessened) by the policy variable. An unintended consequence of a policy, however, implies that the outcome variable (e.g. ED crowding) is inadvertently impacted in an undesirable way (e.g. ED crowding is worsened).

Clearly, any feedback loops in which the outcome variable is embedded will impact the influence of a change in the policy variable. Any balancing loops will reduce the impact of changes of the policy variable on outcomes while reinforcing loops will increase the impact. Such feedback loops will, however, not alter the direction of change due to the impact of a policy variable. The path analysis can therefore correctly identify intended and unintended policy consequences.

## Data sources

The construction of the CLD is primarily based on consultations with ED experts at the symposium *State of Emergency Medical Care in Singapore* held in April 2015 and a review of the corresponding report authored by the 'State of Emergency Medical Care in Singapore' workgroup.<sup>9</sup> Furthermore, this study heavily profited by one co-author's expertise as the director of research in the department of emergency medicine of a large acute tertiary hospital in Singapore. Finally, this study drew information on ED crowding from direct observation in an ED and from a thorough literature review in high-impact academic journals.

## Core model structure

Figure 3 shows the core structure of the CLD we developed. The starting point of the modelling process was the observation that ED crowding is a disequilibrium between demand and supply of emergency medicine services within the ED and limited hospital capacity.<sup>2,3</sup> As mentioned in the introduction, restrictions in hospital capacity cause admitted ED patients to 'board' or 'lodge' inside the ED. These two main causes for ED crowding are reflected in variables 1, *demand-supply gap in the ED*, and 9, *ED boarding of inpatients*, in the model.

In Singapore, demand for emergency services may be split into two broad categories: P1 and P2 patients needing 'critical' ED care (variable 8), and P3 and P4 patients needing 'stable' ED care (variable 7). Incoming patients are classified according to the patient acuity category scale (PACS), where P1 denotes the most acutely ill individuals needing immediate attention, P2 refers to acutely ill individuals with severe symptoms, and P3 and P4 are individuals with stable emergencies and less acutely ill patients, respectively.<sup>23</sup> Of all the ED attendances in Singapore, approximately 7% are classified as P1, 40% are P2, 52% are P3, and 1% are P4.<sup>9</sup>

In the model, supply of emergency services (variable 2) depends on the size of the ED (variable 3), the number of junior and senior ED staff (variables 4 and 6), and the



average productivity of the entire ED workforce (variable 5). It was assumed that senior clinicians are more productive than junior clinicians.<sup>24</sup> In addition, the model takes into account that juniors will become seniors over time increasing the average productivity of the ED workforce.

Previous research has shown that ED crowding influences *quality of ED care* (variable 11), *waiting time for EP's consult* (variable 13), and creates *ED patients who leave without being seen* (variable 12).<sup>3</sup> Ambulance diversion, another frequently mentioned effect of ED crowding in the literature, is not allowed in Singapore and patients are always brought to the closest hospital; ambulance diversion is therefore not included in the model.<sup>9</sup> Ultimately, these consequences of ED crowding impact *ED patient satisfaction* (variable 14) and *ED patients' health outcomes* (variable 15).

### Expanded model structure

We expanded the model by gradually increasing the model boundary thereby asking questions such as: 'What are other consequences of a *demand-supply gap in the ED* than crowding?' or 'Which factors influence the *demand for stable ED care* and the *demand for critical ED care*?' The complete structure of the developed CLD is depicted in Figure 4. In the CLD, the number of patients with stable ED care needs also relates to their *utilization of primary care* (variable 22) and their *social care needs* (variable 29). Patients' *utilization of primary care* is a function of its relative attractiveness (variable 23) compared to other health services providers. In contrast, the number of patients with critical ED care needs depends *inter alia* on the *prevalence of chronic disease* (variable 33) in Singapore. As the Singaporean population grows (variable 32) and ages (variable 31) rapidly, patients with chronic medical conditions are expected to make up an increasing proportion of the ED workload in the future.<sup>25-27</sup>

A key aspect of the expanded model structure is that an increasing *demand-supply gap in the ED* leads to a rising *ED workload* (variable 16). Rising *ED workload* creates instantaneously more stress (variable 17) and less satisfied ED staff (variable 18) in the long run. As a consequence, average productivity of the ED workforce (variable 5) falls and senior (variable 4) and junior (variable 6) ED staff leave.<sup>28</sup> In the short run, however, a growing *ED workload* can be compensated to a certain extent by ED staff becoming more productive.

A further cause of the increasing *ED workload* is the expanding *scope of service provided by ED staff* (variable 37) in Singapore. More and more emergency services are offered by the ED workforce due to *ED adoption of medical-technical innovations* (variable 39) such as geriatric emergency medicine or emergency ultrasound and rising *ED patients' expectations* (variable 40) and *complexity of ED patients* (variable 38).<sup>9</sup>

For the purpose of diagram clarity and to avoid a 'crowded' diagram in Figure 4, we duplicated four variables, that is,

generated so-called shadow variables. These variables are *ED patient satisfaction* (variable 14), *stress level imposed on ED staff* (variable 17), *attrition of ED staff* (variable 20), and *scope of service provided by ED staff* (variable 37). The respective variables names are bold and underlined in Figure 4. In addition, a description of nine key feedback loops, denoted by capitalized letters 'B' (balancing) and 'R' (reinforcing) in Figure 4, can be found in Table 3 in Appendix 1.

### Policy analysis

Based on the full CLD shown in Figure 4, we test three different policies in their impact to reduce ED crowding that are presently discussed by policy-makers in Singapore:<sup>9</sup>

- Introduction of geriatric emergency medicine in EDs to enable more efficient and effective treatment of the increasing number of elderly patients. This policy is reflected in variable 39, *ED adoption of medical-technical innovations*, in the CLD.
- Expansion of ED staff training to increase the supply of junior ED manpower. This policy is represented in variable 6, *junior ED staff*, in the CLD.
- Implementation of enhanced primary care to enable treatment of a large fraction of P3 and all P4 patients outside the ED. This policy is mirrored in variable 25, *access to primary care*, in the CLD.

As previously discussed, we examine the impact of these policies by performing a 'path analysis' that reveals both their intended and unintended (side) effects on the outcome variable *ED crowding* (variable 10) in the model.

### Results

Table 2 summarizes the results of the path analysis illustrating the potential intended and unintended consequences of each policy based on the CLD in Figure 4. Intended and unintended policy consequences are further classified into short-term and long-term effects. All these policy consequences are directly linked to the CLD in Figure 4 and therefore depend on the model's construction. This implies that any changes made to the CLD, for example, introducing new variables and/or relationships, will lead to different policy consequences.

Pursuing the first policy – introduction of geriatric emergency medicine in EDs – has eight different potential intended consequences which all reduce *ED crowding* (variable 10). However, the same policy, exhibits 10 possible unintended consequences that all worsen *ED crowding*. In contrast, pursuing the second policy – expansion of ED staff training – shows five possible intended consequences that all diminish *ED crowding*. This policy, though, also triggers five possible unintended consequences that exacerbate *ED crowding*. Finally, pursuing the third policy – implementation of enhanced

**Table 2.** Path analysis revealing potential intended and unintended consequences of policies on ED crowding (variable 10).

Intended consequence(s) of policy		Unintended consequence(s) of policy	
<i>Introduction of geriatric emergency medicine in EDs (variable 39)</i>			
No	P <sup>a</sup> D Path <sup>b</sup>	No	P D Path
Short-term	1 - 6 39 → 37 → 11 → 15 → 8 → 1 → 10	1 + 8 39 → 37 → 16 → 17 → 11 → 15 → 8 → 1 → 10	
	2 - 6 39 → 37 → 16 → 5 → 2 → 1 → 10		
Long-term	3 - 13 39 → 37 → 16 → 17 → 11 → 14 → 23 → 22 → 7 → 1 → 10	2 + 11 39 → 37 → 11 → 14 → 23 → 22 → 7 → 1 → 10	
	4 - 13 39 → 37 → 16 → 17 → 18 → 20 → 6 → 5 → 2 → 1 → 10	3 + 11 39 → 37 → 16 → 17 → 18 → 5 → 2 → 1 → 10	
	5 - 13 39 → 37 → 16 → 17 → 18 → 20 → 4 → 6 → 2 → 1 → 10	4 + 12 39 → 37 → 16 → 17 → 18 → 20 → 4 → 2 → 1 → 10	
	6 - 13 39 → 37 → 16 → 17 → 18 → 20 → 21 → 6 → 2 → 1 → 10	5 + 12 39 → 37 → 16 → 17 → 18 → 20 → 6 → 2 → 1 → 10	
	7 - 17 39 → 37 → 16 → 17 → 18 → 20 → 21 → 6 → 4 → 2 → 1 → 10	6 + 13 39 → 37 → 16 → 17 → 18 → 20 → 4 → 5 → 2 → 1 → 10	
	8 - 18 39 → 37 → 16 → 17 → 18 → 20 → 21 → 6 → 4 → 5 → 2 → 1 → 10	7 + 14 39 → 37 → 16 → 17 → 18 → 20 → 4 → 6 → 5 → 2 → 1 → 10	
		8 + 14 39 → 37 → 16 → 17 → 18 → 20 → 21 → 6 → 5 → 2 → 1 → 10	
		9 + 16 39 → 37 → 16 → 17 → 18 → 20 → 6 → 4 → 2 → 1 → 10	
		10 + 17 39 → 37 → 16 → 17 → 18 → 20 → 6 → 4 → 5 → 2 → 1 → 10	
<i>Expansion of ED staff training (variable 6)</i>			
No	P D Path	No	P D Path
Short-term	1 - 3 6 → 2 → 1 → 10	1 + 4 6 → 5 → 2 → 1 → 10	
	2 - 5 6 → 16 → 5 → 2 → 1 → 10	2 + 7 6 → 16 → 17 → 11 → 15 → 8 → 1 → 10	
	3 - 7 6 → 4 → 2 → 1 → 10		
	4 - 8 6 → 4 → 5 → 2 → 1 → 10		
Long-term	5 - 12 6 → 16 → 17 → 11 → 14 → 23 → 22 → 7 → 1 → 10	3 + 10 6 → 16 → 17 → 18 → 5 → 2 → 1 → 10	
		4 + 11 6 → 16 → 17 → 18 → 20 → 4 → 2 → 1 → 10	
		5 + 12 6 → 16 → 17 → 18 → 20 → 4 → 5 → 2 → 1 → 10	
<i>Implementation of enhanced primary care (variable 25)</i>			
No	P D Path	No	P D Path
Short-term	1 - 8 25 → 23 → 22 → 7 → 1 → 10		

No: number; P: polarity of path/relative impact of path; D: relative delay of path; -: negative; +: positive.

<sup>a</sup>Negative polarity means that the more of a policy is implemented the less ED crowding is.

<sup>b</sup>Numbers correspond to variable numbers in Figure 4.

primary care – has only one possible intended consequence that ameliorates *ED crowding* within the boundary of the CLD in Figure 4.

To illustrate how to read Table 2, consider, for example, the first path belonging to the eight potential intended consequences of introducing geriatric emergency medicine in EDs: 39 → 37 → 11 → 15 → 8 → 1 → 10. This path contains seven variables and connects *ED adoption of medical-technical innovations* (variable 39) with *ED crowding* (variable 10). In addition, this path has a relative delay of six, that is, it is a short-term effect, and it has a negative polarity, that is, the more EDs adopt medical-technical innovations the less ED crowding is. The path reads as follows: introducing geriatric emergency medicine will lead to *ED adoption of medical-technical innovations* (variable 39) causing the *scope of service provided by the ED staff* (variable 37) to increase. Consequently, the *quality of ED care* (variable 11) and *ED patients' health outcome* (variable 15) may improve. This is likely to decrease *demand for critical ED care* (variable 8) further reducing the *demand-supply gap in the ED* (variable 1) and ultimately *ED crowding* (variable 10).

However, introducing geriatric emergency medicine in EDs shows beside desired consequences such as improved quality of care possible unwanted side effects. Consider, for example, the first path representing an unintended consequence of this policy depicted on the right side of Table 2: 39 → 37 → 16 → 17 → 11 → 15 → 8 → 1 → 10. This path means that introducing geriatric emergency medicine will lead to *ED adoption of medical-technical innovations* (variable 39) causing the *scope of service provided by ED staff* (variable 37) to increase. Consequently, *ED workload* (variable 16) and the *stress level imposed on ED staff* (variable 17) may rise. This is likely to compromise *quality of ED care* (variable 11) and *ED patients' health outcomes* (variable 15) further adding to the *demand for critical ED care* (variable 8). Ultimately, this may increase both the *demand-supply gap in the ED* (variable 1) and *ED crowding* (variable 10) counteracting the positive impact of the path described in the previous paragraph.

The second possible unintended policy consequence relates to quality of ED care and attractiveness of primary care. In short, it describes how rising standards in ED care causes the *relative attractiveness of primary care* (variable 23) to fall. As a consequence, *utilization of primary care* (variable 22) decreases further adding to the *demand for stable ED care*. Again this may increase both the *demand-supply gap in the ED* and *ED crowding*. Other potential unwanted policy consequences, illustrated in paths 3–10, are linked to the effects of a rising *ED workload* due to the implementation of geriatric emergency medicine. A rising *ED workload* may diminish *satisfaction of ED staff* (variable 18) causing *average productivity of ED staff* (variable 5) to decrease and *attrition of ED staff* (variable 20) to increase, both worsening *ED crowding*.

Expanding ED staff training has similarly also potential unintended policy consequences because it implies more work for ED staff due to educational purposes. Rising teaching duties

for ED manpower increases stress and reduces job satisfaction. This causes the attrition rate to rise and senior ED staff to resign deteriorating the mismatch between demand and supply for emergency services and crowding (paths 4 and 5). Additionally, expanding ED staff training reduces the overall ED productivity in the short-term because junior ED staff is less productive than senior ED staff (path 1). Other possible unintended side effects are illustrated in paths 2 and 3 in Table 2.

In this study, enhancing primary care was the only policy with no unintended consequences, considering the boundary of our CLD. Accordingly, the implementation of enhanced primary care possibly has a salutary impact on *ED crowding*, that is, it lessens *ED crowding* without any restrictions.

## Discussion

### Main findings

In this study, we explored ED crowding in Singapore from a systems thinking perspective to account for the problem's complexity caused by a web of interrelated issues.<sup>28</sup> We used causal loop diagramming to visualize these interrelations among variables affecting and affected by ED crowding. The resulting CLD is an attempt to better understand the dynamic nature of this phenomenon and it can serve as a 'boundary object' for policy discussions among health care decision-makers.<sup>29</sup> Furthermore, it can be used as a conceptual framework for further research efforts similarly to the 'input-throughput-output' model.<sup>2</sup>

The path analysis examined the likely intended and unintended consequences of three policies currently under consideration in Singapore: introduction of geriatric emergency medicine in EDs, expansion of ED staff training, and implementation of enhanced primary care. The analysis demonstrated that enhancing primary care in Singapore is distinctive in potentially reducing ED crowding because it has no apparent side effects according to the CLD in Figure 4. In Singapore, the primary health care sector has potential for enhancement. Anecdotally, many patients who could be treated appropriately in a primary care clinic prefer going to the ED which they can access 24 h a day and has all the diagnostic equipment – which most single practice general practitioners (GPs) lack – at a reasonable cost.<sup>30</sup> This is reflected by the observation that over half of ED patient visits are categorized as P3 and P4.<sup>9</sup> While others conclude that redirecting non-urgent patients is ineffective,<sup>12</sup> we postulate that diverting a larger fraction of P3 and P4 patients to the primary health care sector may substantially relieve EDs in Singapore.

Both the policy of introducing geriatric emergency medicine and of expanding ED staff training were associated with causal paths representing unintended, that is, undesirable, side effects. In particular, both policies suggest a higher ED workload leading to more stress which if endured for a longer period may cause staff dissatisfaction and burnout. This effect would likely appear in the beginning of policy implementation and could lead to failure as it stresses a health care system which is already stretched close to its limits.<sup>9</sup>



## Limitations

This study is based on the analysis of a CLD, a qualitative and simplified model of a real-world problem and necessarily does not capture the whole reality. Some phenomena may not been included in the CLD or are oversimplified. Thus, the value of the policy analysis is highly linked to the accuracy of the model's representation of ED crowding. However, the CLD captures a substantial range of factors and provides a valuable starting point for further discussion and decision-making.

While the path analysis allows to identify the intended and unintended consequences of different policies, it does not allow to measure the overall policy impact and therefore to assess policy effectiveness. To measure the overall impact of a policy would require the quantitative analysis of the interaction of all the feedback loops in the CLD. Feedback loops modify the effect of the impact of policy levers on the outcome variable. The effect of any policy to reduce ED crowding is lessened by balancing loops such as the one linking ED crowding to the number of *ED patients who leave without being seen* (balancing loop B3) and strengthened by reinforcing loops such as the loop describing the increase in demand for critical ED care due to a reduction in the quality of ED care (reinforcing loop R5). Moreover, feedback processes involving the intermediate variables in a path will also modify the magnitude (though not the direction) of the impact of policy levers.

Also, this model assumes that each policy is equally easy to implement and does not account for real-world issues in implementation. For example, enhancing primary care might be more demanding to implement compared to the other policy options. Additionally, the model ignores the factor of patient choice, as patients may still not choose to go for primary care even with enhancement in preference to the ED.

## Future research

In addition to further validating the CLD, future research might try to parametrize the CLD's variables and interrelations to enable the construction of a simulation model using the 'system dynamics' methodology.<sup>14</sup> This allows for a more nuanced analysis of ED crowding because it provides a quantitative estimate of the relative importance of the phenomena reflected in CLD paths and allows us to simulate system change in response to policy actions. A quantitative model will allow to take into account the interaction of all the feedback effects which modify the magnitude of the impact of the policy levers on the outcome variable. A quantitative model will also permit to assess the combined effect of the implementation of one or more policy options onto the outcome variable considering the magnitude of all the intended and unintended consequences of these policies. Such a quantitative simulation can be exceedingly useful in the formation of health care policy.<sup>31</sup>

## Conclusion

ED crowding is a health care problem observable in many health care systems and reflects a local manifestation of a larger systemic disease within a health care system. In this study, we approached the problem using a systems thinking approach to account for its complex and holistic nature. Causal loop diagramming was a powerful tool for eliciting the systemic structure of ED crowding, illustrating the interrelations between its drivers and consequences. Furthermore, the resulting CLD proved useful in evaluating three different policies currently debated by policy-makers in Singapore, in particular demonstrating vividly, both intended and unintended consequences of policy proposals.

## Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

## References

1. Di Somma S, Paladino L, Vaughan L, et al. Overcrowding in emergency department: an international issue. *Intern Emerg Med* 2015; 10: 171–175.
2. Asplin BR, Magid DJ, Rhodes KV, et al. A conceptual model of emergency department crowding. *Ann Emerg Med* 2003; 42: 173–180.
3. Hoot NR and Aronsky D. Systematic review of emergency department crowding: causes, effects, and solutions. *Ann Emerg Med* 2008; 52: 126–136.
4. Moskop JC, Sklar DP, Geiderman JM, et al. Emergency department crowding, part 1: concept, causes, and moral consequences. *Ann Emerg Med* 2009; 53: 605–611.
5. Hsia RY, Kellermann AL and Shen Y. Factors associated with closures of emergency departments in the United States. *JAMA* 2011; 305: 1978–1985.
6. Institute of Medicine. *Future of emergency care: hospital-based emergency care at the breaking point*. Washington, DC: National Academies Press, 2006.
7. Department of Health. *The NHS Plan: a plan for investment, a plan for reform*. Norwich: Department of Health, 2000.
8. Department of Statistics Singapore. Monthly digest of statistics Singapore: January 2016, <http://www.tablebuilder.singstat.gov.sg/publicfacing/createDataTable.action?refId=1347> (2016, accessed 23 September 2016)
9. State of Emergency Medical Care in Singapore Workgroup. *State of emergency medical care in Singapore: addressing challenges and charting directions*. Singapore: College of Emergency Physicians, Academy of Medicine, Singapore and Society for Emergency Medicine in Singapore, 2015.
10. Ministry of Health Singapore. Admissions and outpatient attendances, [https://www.moh.gov.sg/content/moh\\_web/home/statistics/Health\\_Facts\\_Singapore/Admissions\\_and\\_Outpatient\\_Attendances.html](https://www.moh.gov.sg/content/moh_web/home/statistics/Health_Facts_Singapore/Admissions_and_Outpatient_Attendances.html) (2015, accessed 19 October 2015).

11. Counselman FL, Marco CA, Patrick VC, et al. A study of the workforce in emergency medicine. *Am J Emerg Med* 2007; 2009(27): 691–700.
12. Myth: Emergency room overcrowding is caused by non-urgent cases. *J Health Serv Res Policy* 2010; 15: 188–189.
13. Adam T and de Savigny D. Systems thinking for strengthening health systems in LMICs: need for a paradigm shift. *Health Policy Plan* 2012; 27 (Suppl. 4): iv1–iv3.
14. Taylor K, Dangerfield B and Le Grand J. Simulation analysis of the consequences of shifting the balance of health care: a system dynamics approach. *J Health Serv Res Policy* 2005; 10: 196–202.
15. Peters DH. The application of systems thinking in health: why use systems thinking? *Health Res Pol Syst* 2014; 12: 51.
16. Sterman JD. *Business dynamics: systems thinking and modeling for a complex world*. Boston, MA: McGraw-Hill Higher Education, 2000.
17. Agyepong IA, Kodua A, Adjei S, et al. When ‘solutions of yesterday become problems of today’: crisis-ridden decision making in a complex adaptive system (CAS) – the Additional Duty Hours Allowance in Ghana. *Health Policy Plan* 2012; 27 (Suppl. 4): iv20–iv31.
18. Axelrod RM. *Structure of decision: the cognitive maps of political elite*. Princeton, NJ: Princeton University Press, 1976.
19. Montibeller G and Belton V. Causal maps and the evaluation of decision options: a review. *J Oper Res Soc* 2006; 57: 779–791.
20. Kampmann CE. Feedback loop gains and system behavior. *Syst Dynam Rev* 1996; 2012(28): 370–395.
21. Richardson GP. Loop polarity, loop dominance, and the concept of dominant polarity. *Syst Dynam Rev* 1984; 1995(11): 67–88.
22. Schoenenberger L, Schmid A and Schwaninger M. Towards the algorithmic detection of archetypal structures in system dynamics. *Syst Dynam Rev* 2015; 31: 66–85.
23. Paul P, Heng BH, Seow E, et al. Predictors of frequent attenders of emergency department at an acute general hospital in Singapore. *Emerg Med J* 2010; 27: 843–848.
24. Thornton V and Hazell W. Junior doctor strike model of care: reduced access block and predominant Fellow of the Australasian College for Emergency Medicine staffing improve emergency department performance. *Emerg Med Australas* 2008; 20: 425–430.
25. Abualenain J, Richardson D, Mountain D, et al. International perspectives on emergency care. In: Pines JM, Abualenain J, Scott J, et al. (eds) *Emergency care and the public’s health*. Chichester: John Wiley & Sons, 2014, pp. 21–44.
26. Kelley ML, Parke B, Jokinen N, et al. Senior-friendly emergency department care: an environmental assessment. *J Health Serv Res Policy* 2011; 16: 6–12.
27. Ansah JP, Eberlein RL, Love SR, et al. Implications of long-term care capacity response policies for an aging population: a simulation analysis. *Health Policy* 2014; 116: 105–113.
28. Derlet RW and Richards JR. Overcrowding in the nation’s emergency departments: complex causes and disturbing effects. *Ann Emerg Med* 2000; 35: 63–68.
29. Black LJ. When visuals are boundary objects in system dynamics work. *Syst Dynam Rev* 2013; 29: 70–86.
30. Khoo HS, Lim YW and Vrijhoef HJ. Primary healthcare system and practice characteristics in Singapore. *Asia Pac Fam Med* 2014; 13: 8.
31. Taylor K and Lane DC. Simulation applied to health services: opportunities for applying the system dynamics approach. *J Health Serv Res Policy* 1998; 3: 226–232.

## Appendix I

**Table 3.** Description of key feedback loops in the expanded model structure.

Loop	Loop name	Loop description
R1	Resignation of seniors	An increasing demand-supply gap leads to more stress and less satisfied senior ED staff. As a consequence, they leave which worsens the demand-supply gap.
R2	Resignation of juniors	An increasing demand-supply gap leads to more stress and less satisfied junior ED staff. As a consequence, they leave which worsens the demand-supply gap.
R3	Job performance degradation	Falling satisfaction of ED staff compromises their average productivity. This reduces the supply of ED care and aggravates the demand-supply gap.
R4	Juniors are less productive than seniors	Hiring of junior ED staff reduces the average productivity of the entire ED staff (assuming a constant ED staff size). As a consequence, supply of ED care falls which compromises the demand-supply gap.
R5	Erosion of quality of ED care	ED crowding causes the quality of ED care to fall which in turn compromises ED patients’ health outcomes. As a consequence, the demand for ‘critical’ ED care rises which worsens the demand-supply gap.
R6	Untreated ED patients	ED crowding leads to ED patients who leave without being seen. This in turn worsens ED patients’ health outcomes and increases demand for ‘critical’ ED care both making the demand-supply gap bigger.
B1	Temporary job performance rise	An increasing workload in the ED can be compensated to a certain extent by physicians and nurses becoming more productive (tipping point).
B2	Juniors filling the gap	Hiring ED junior staff increases the supply of ED care. As a consequence, the demand-supply gap can be reduced.
B3	Relief of untreated ED patients	ED patients who leave without being seen alleviate ED crowding.

ED: Emergency Department.