Expert Consensus

Systems mapping: a novel approach to national lung cancer screening implementation in Australia

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Background: Lung cancer screening with low-dose computed tomography has been started in some high-income countries and is being considered in others. In many settings uptake remains low. Optimal strategies to increase uptake, including for high-risk subgroups, have not been elucidated. This study used a system dynamics approach based on expert consensus to identify (I) the likely determinants of screening uptake and (II) interactions between these determinants that may affect screening uptake.

Methods: Consensus data on key factors influencing screening uptake were developed from existing literature and through two stakeholder workshops involving clinical and consumer experts. These factors were used to develop a causal loop diagram (CLD) of lung cancer screening uptake.

Results: The CLD comprised three main perspectives of importance for a lung cancer screening program: participant, primary care, and health system. Eight key drivers in the system were identified within these perspectives that will likely influence screening uptake: (I) patient stigma; (II) patient fear of having lung cancer; (III) patient health literacy; (IV) patient waiting time for a scan appointment; (V) general practitioner (GP) capacity; (VI) GP clarity on next steps after an abnormal computed tomography (CT); (VII) specialist capacity to accept referrals and undertake evaluation; and (VIII) healthcare capacity for scanning and reporting. Five key system leverage points to optimise screening uptake were also identified: (I) patient stigma influencing willingness to receive a scan; (II) GP capacity for referral to scans; (III) GP capacity to increase patients' health literacy; (IV) specialist capacity to connect patients with timely treatment; and (V) healthcare capacity to reduce scanning waiting times.

Conclusions: This novel approach to investigation of lung cancer screening implementation, based on Australian expert stakeholder consensus, provides a system-wide view of critical factors that may either limit or promote screening uptake.

Keywords: Lung neoplasms; mass screening; Delivery of Health Care; system dynamics

Submitted May 13, 2024. Accepted for publication Sep 06, 2024. Published online Oct 28, 2024.
doi: 10.21037/tlcr-24-425
View this article at: https://dx.doi.org/10.21037/tlcr-24-425

Introduction

In 2020, lung cancer accounted for an estimated 2.2 million new cases and 1.8 million deaths, representing 18% of all cancer deaths globally (1). In Australia, lung cancer is the fourth most diagnosed cancer (13,810 new cases in 2021) and the leading cause of cancer-related deaths in both men and women. In 2021, an estimated 8,693 people died from lung cancer in Australia, accounting for 19% of all cancer deaths (2). When detected at stage I, lung cancer has a 67.7% five-year survival compared to 17.1% and 3.2% for stages III and IV (3). Early-stage lung cancer is usually asymptomatic, and most lung cancers (70%) are diagnosed at a later stage when patients present after symptoms appear, with limited curative treatment options available and poorer survival prognosis (4,5). Screening asymptomatic participants who are at higher risk therefore provides an opportunity to detect lung cancer earlier and potentially improve survival (6).

Highlight box

Key recommendations

- Increase awareness about lung cancer screening.
- Reduce patient stigma associated with lung cancer.
- Ensure healthcare capacity for scanning and follow-up treatment.

What was recommended and what is new?

- Increase awareness about lung cancer screening.
- Address patient stigma on lung cancer.
- Ensure adequate healthcare capacity.
- Reduce patient stigma influencing willingness to accept to receive a scan.
- Increase general practitioner (GP) capacity to allow for more referrals for scans, and to increase patients' health literacy and their willingness to accept a scan.
- Increase specialist capacity to ensure patients are connected with treatment in timely manner.
- Increase healthcare capacity to reduce waiting times for a scan.

What is the implication, and what should change now?

- The success of a lung cancer screening program depends on a holistic view and consideration of the participant, primary care, and health system perspectives together.
- Implementing public campaigns to increase awareness about lung cancer screening and reduce stigma associated with lung cancer.
- Increasing GP and specialist capacity to manage the expected increase in screenings and potential follow-up treatment.
- Offer standards to improve clarity for GPs on next steps after abnormal computed tomography scan.
- Improve healthcare infrastructure for scanning to reduce waiting times for patients.

Over the past two decades, evidence from large randomised controlled trials have shown that screening people at high risk with low-dose computed tomography (LDCT) can reduce lung cancer mortality through shifting diagnosis from late to earlier-stages (7,8). Based on evidence from these trials, health systems worldwide have initiated, or are considering, the implementation of nationwide or jurisdictional lung cancer screening programs to identify early-stage lung cancer by screening asymptomatic participants at high risk (9). However, lung cancer screening is complex, and the success of effective nationwide screening programs depends on an array of factors. In settings where a population-based screening program has already been implemented, uptake has been variable. For example, only 16.3% of eligible participants in the USA have participated in lung cancer screening (10). This highlights the need to better understand the factors that influence the uptake of screening.

Australia is currently preparing for the implementation of a national lung cancer screening program to commence by mid-2025, comprising biennial LDCT scans among high-risk individuals (defined as aged 50–70 years, a smoking history of at least 30 pack-years; and a current or former smoker who has quit within the past 10 years) (11). Currently, in Australia 12% of lung cancers are diagnosed at stage I (4). It is estimated that in the first 10 years of a national risk-based screening program around 70% of detected lung cancers could be diagnosed at an early stage, implying the prevention of over 12,000 deaths due to lung cancer and reduction of 20% in lung cancer mortality in Australia (12).

The Australian healthcare system is characterised by its nominally universal system, although providers are both public and private suppliers. The Australian Commonwealth has oversight of the primary care sector across the nation, which is usually the first point of contact for the patient, similar to the UK, Canada and the US. Primary care providers in Australia are privately operated, but are subsidised by the federal government to different degrees, with some offering free services ('bulk billed') to consumers. Referrals to a specialist are required by a general practitioner (GP) and are within State jurisdiction (13). The national lung cancer screening program will be funded by the Australian Medicare fund.

With Australia moving towards the implementation of a nationwide lung cancer screening program, it is critical to understand the factors that may enable or impede screening uptake in this context, from the participant, healthcare provider and health system perspective. Most research to

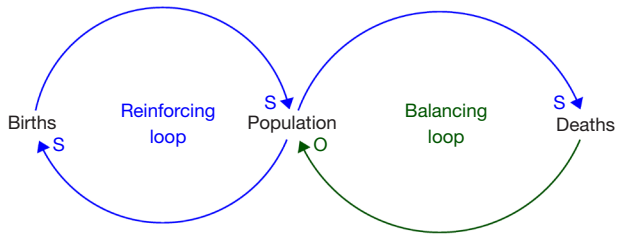

Figure 1 Reinforcing (positive) and balancing (negative) feedback loops. 'S' = relationship between two variables change in the same direction. 'O' = variables change in the opposite direction (i.e., an increase in one variable causes a decrease in the connected variable).

date has focused on qualitative studies to investigate these factors (14), and have been conducted in settings where a screening program had already been implemented (e.g., USA). Patient barriers encompass concerns like the fear of having lung cancer, lack of awareness and stigma associated with smoking (15). Healthcare providers encounter obstacles such as time constraints, insufficient information about screening, and nihilism related to treatment of lung cancer (16). On a systemic level, limited resources to support screening, including equipment and personnel, represent a significant barrier (14). Furthermore, the different perspectives have only been investigated in isolation, failing to account for their interdependencies. Consequently, there is a need to understand how the factors at the participant, healthcare provider and health system level interact and mutually influence screening uptake. Traditional analytic methods employed in program design and evaluation often overlook, or are unable, to capture these interactions (17).

A participatory system dynamics approach was used for this study. System dynamics aims to identify the interconnections between feedbacks and non-linear relationships that explain why a 'system' is behaving in a certain way (18). This can be achieved through mapping and modelling a 'system' using a variety of sources of evidence such as research, expert and local stakeholder knowledge; practice experience; and data to quantify a complex problem (19). A comprehensive representation of system complexity can inform lung cancer screening program design and implementation, through examining the likely non-linear interactions between system components such as individual behaviours and preferences, social and economic context, clinical decision making, and health system capacity. In dynamically complex systems, cause and effect are often distant in time and space, and can involve circular feedbacks and time delays for effects to emerge (19).

In health research, system dynamics models have been applied in a range of contexts including obesity, human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS), cancer screening, suicide prevention, and COVID-19 (20-23). Cancer screening is an area that is particularly suited for system dynamics modelling, due to potential nonlinearities in the system, delayed feedback, and the delays associated with translation of evidence and policy implementation (19). The present study uses a participatory system dynamics approach based on expert consensus data that aims to capture the complexity of interacting factors that may impact the success of a future screening program (18). Thus, the aims of this study were to (I) identify the likely determinants of lung cancer screening uptake, and (II) identify the relationships and dynamic behaviours between these determinants that may influence the uptake of lung cancer screening in Australia.

Methods

Creating a causal loop diagram (CLD)

A CLD can help to better understand what mechanisms drive system behaviour through visually mapping the feedback loops that exist in the 'system' (19). Feedback loops connect chains of variables with arrows and 's' or 'O' signs to indicate the direction of the influence. A 's' sign indicates the relationship between two variables changing in the same direction (i.e., an increase in one variable causes an increase in the connected variable, or a decrease in one variable causes a decrease in the connected variable, respectively). An 'O' sign indicates that variables change in the opposite direction (i.e., an increase in one variable causes a decrease in the connected variable) (18). A '⫣⫢' sign indicates a time delay between cause and effect of two variables. Feedback loops are either positive or negative depending on whether the original variable in the loop will grow or decrease after involving a chain of action (24). Positive feedback loops self-reinforce or amplify behaviour (i.e., exponential growth or decline) whereas negative feedback loops are counteracting or balancing. *Figure 1* demonstrates an example where an increase in births leads to an increase in the population, whereas an increase in deaths will lead to a decrease in the population. Complex systems consist of connections between these feedbacks, and dynamic behaviour arises from the interactions of these loops (19). CLDs are useful in understanding complex problems and identifying key

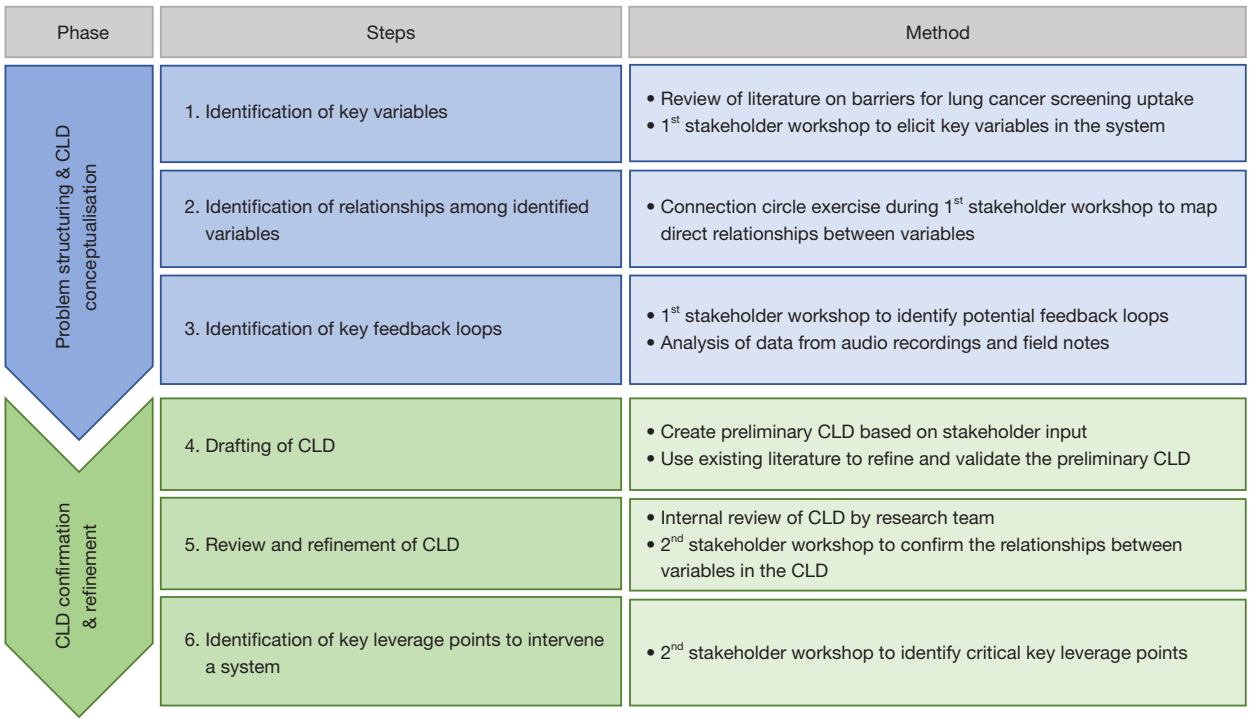

Figure 2 Flowchart for methodological steps. CLD, causal loop diagram.

intervention points that can be targeted to optimise system behaviour (25), and can also serve as starting points for engaging stakeholders to discuss policy planning.

Procedures and participants

For the present study, two participatory workshops with key stakeholders were held in early 2023 (Table S1). The first stakeholder workshop was held in January 2023 in Sydney, New South Wales, with six key stakeholders including two specialist lung cancer nurses, a health economist, a GP, a person with experience of lung cancer and a First Nations patient representative. The 4-hour workshop included three sessions comprising a mix of individual, small group and plenary exercises. In the first session, participants were asked to elicit variables that would most likely have an impact on the total number of people screened. The second and third sessions included a connection circle exercise where participants were asked to identify direct relationships between these variables, and then to identify potential feedback loops between variables. Data from the audio recordings were used to cross-check with the field notes. A preliminary CLD was then created by the research team and variables and relationships in the CLD were validated using evidence from existing literature. Searches of the wider literature ensured that proposed connections could be confirmed with evidence from previous studies and were consistent with the literature. The second stakeholder workshop was held in February 2023, where expert consensus was sought to validate the preliminary CLD. Experts comprised ten clinicians specialising in lung cancer care which included six respiratory physicians, a medical oncologist, two specialist lung cancer nurses, a consumer advocate. Two of the participants were also involved in the implementation of lung cancer screening programs in other countries. The CLD was further refined and key leverage points were identified based on feedback and insights from this stakeholder group. The methodological steps are outlined in *Figure 2*.

Results

A CLD was developed based on the information extracted from stakeholders and existing evidence from the literature (*Figure 3* and *Tables 1*,*2*). The CLD comprised three main perspectives of a lung cancer screening program: the health system perspective, primary care perspective and the participant perspective (*Figure 3*). Each of these perspectives

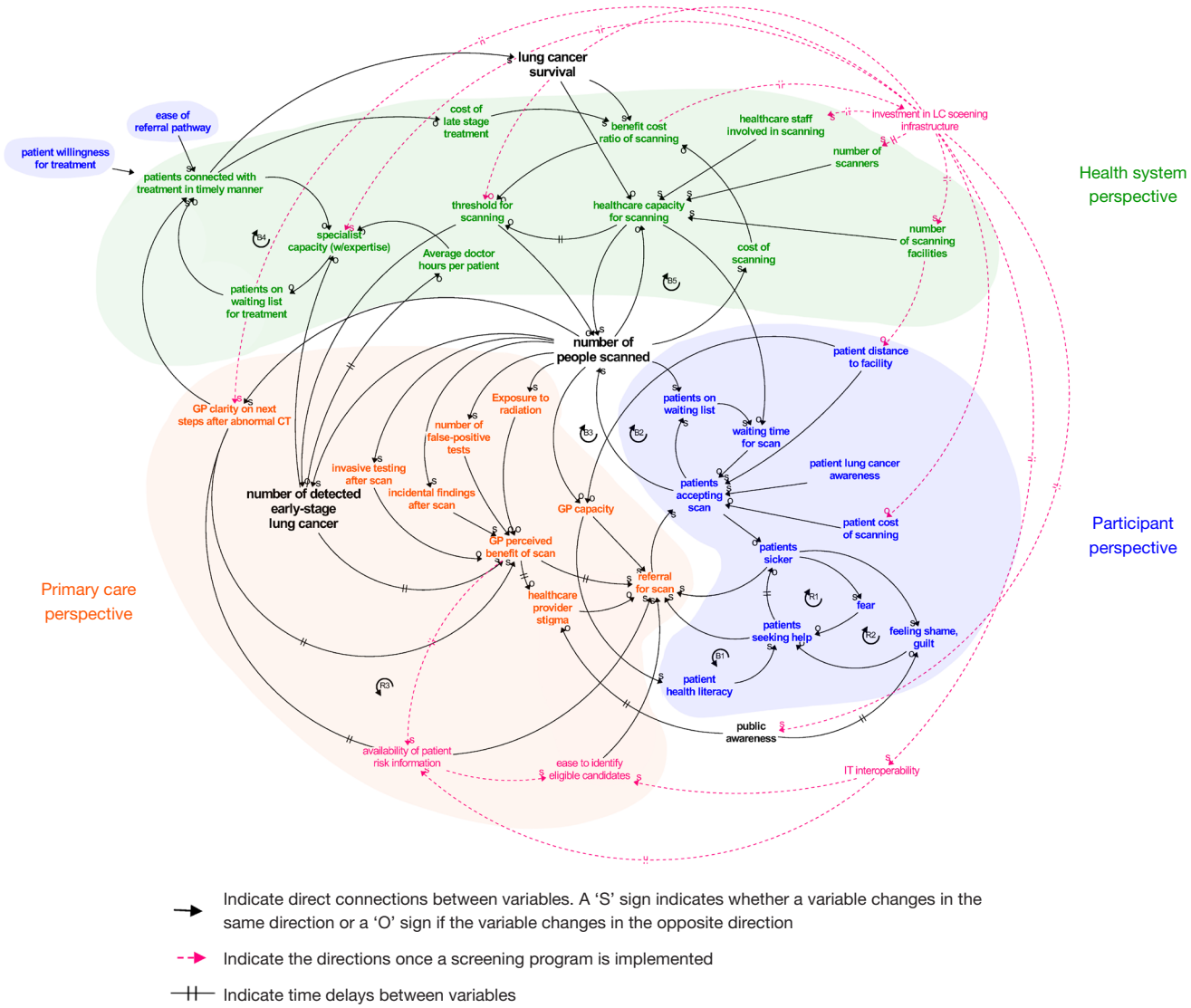

Figure 3 Causal loop diagram of lung cancer screening in Australia. LC, lung cancer; GP, general practitioner; CT, computed tomography; IT, information technology; Specialist capacity w/expertise, specialist capacity with expertise.

included a set of key variables and feedback loops that were identified by stakeholders as responsible drivers for the dynamics impacting the implementation and uptake of lung cancer screening in the Australian context (*Table 1*). The structure of each of these system perspectives and key feedback loops is described in more detail below.

Participant perspective

The participant perspective encompasses the factors that would influence individual decision-making processes and the way individuals choose to interact with the healthcare system. This perspective involved psychological and emotional factors, as well as interactions with the healthcare system, offering insights into how these elements can influence screening uptake. From a participant perspective, there was consensus relating to four dominant feedback loops that likely impact participation.

- Firstly, patient fear of having lung cancer was highlighted as one of the main reasons for why patients might not seek help and consult with a GP. This potentially led to patients becoming sicker, and

Table 1 Variables included in the causal loop diagram

Perspective	Variable
Health system perspective	• Healthcare capacity for scanning
	• Threshold for scanning with LDCT
	• Specialist capacity with expertise in lung cancer
	• Patients connected with treatment in timely manner
	• Patients on waiting list for treatment
	• Cost of late-stage treatment
	• Benefit cost ratio of lung cancer screening
	• Cost of scanning with LDCT
	• Number of LDCT scanners
	• Number of scanning facilities
	• Healthcare staff involved in scanning
	• Average doctor hours per patient
Primary care perspective	• GP capacity
	• Patient referral for a LDCT scan
	• GP perceived benefit of a LDCT scan
	• Healthcare provider stigma
	• Exposure to radiation
	• Number of false-positive tests
	• Incidental findings after a LDCT scan
	• Invasive testing after a LDCT scan
	• GP clarity on the next steps after an abnormal LDCT scan
	• Availability of patient risk information
	• Ease to identify eligible candidates
Participant perspective	• Patients accepting to receive a LDCT scan
	• Number of patients on waiting list
	• Waiting time for an appointment to receive a LDCT scan
	• Health literacy
	• Patient seeking help
	• Fear
	• Feeling of shame and guilt
	• Patients' costs of getting a LDCT scan
	• Patient distance to facility
	• Lung cancer awareness
	• Patient distance to scanning facility
	• Patient willingness for treatment

LDCT, low-dose computed tomography; GP, general practitioner.

not presenting until symptomatic thereby increasing their fear, which is described by reinforcing loop—R1.

- Secondly, stakeholders also reported patients may also not consult with a GP due to shame and guilt because of their smoking status, which in turn would lead to patients becoming sicker and not presenting until symptomatic, leading to increased feeling of shame and guilt (reinforcing loop—R2). The relationship between patient's fear of an abnormal lung cancer scan, their perceived stigma and reluctance to seek help or attend screening has also been reported in previous studies (26-30). It was emphasised by stakeholders that patient perceived stigma would have a significant impact not only on help-seeking behaviour but also on the entire patient journey, from consulting with a GP to follow-up examinations and adhering to treatments. Unlike other types of cancer where the healthy population is being screened based on age (breast, cervical, colorectal), lung cancer screening targets primarily people who smoke. People who smoke may therefore experience stigma due to the perception that lung cancer is preventable and self-inflicted, further reinforced by anti-tobacco campaigns (31,32).
- Thirdly, more health literate patients are more likely to seek help, leading to more referrals for a scan, and more people receiving a scan. With an increase in people scanned there is an anticipated pressure on GP capacity, since patients would need to see the GP again after receiving a scan, which may contribute to decreased time for GPs to educate and inform patients about lung cancer screening (balancing loop—B1). Stakeholders referred to the important role GPs play in increasing health literacy. A lack of GP capacity has also been previously reported in a United Kingdom (UK) study to be a barrier for lung cancer screening, particularly in culturally diverse communities with lower socio-economic status (33). This emphasises the need for a screening program that considers health literacy and is focused on health equity to reduce health disparities.
- Finally, stakeholders noted participant waiting times as an important driver, with long waiting times for patients to receive an appointment for a scan (e.g., up to 6 months) can be associated with patients declining a scan (balancing loop—B2), which in turn drives the waiting time for a scan to reach a relative equilibrium.

Other factors of relevance that were identified that may

Table 2 Key feedback loops responsible for the system behaviour

Loop number	Key concept	Variables in loop
R1	Fear of having lung cancer leads to patients not seeking help making them sicker	Fear → (O) patients seeking help → (O) patients getting sicker → (S) fear
R2	Feeling of shame and guilt leads to patients not seeking help making them sicker	Feeling of shame and guilt → (O) patients seeking help → (O) patients getting sicker → (S) feeling of shame and guilt
B1	The more patients are health literate the more people are getting scanned reducing GP capacity which reduces likelihood to educate patients and increase health literacy	Patient health literacy → (S) patients seeking help → (S) referral for scan → (S) patients accepting scan → (S) number of people scanned → (O) GP capacity → (O) patient health literacy
B2	Increase in number of patients getting a LDCT scan increases the number of patients on waiting list and time to get a scan which leads to patients' unwillingness to get a scan	Patients accepting scan → (S) number of people scanned → (S) patients on waiting list →(S) waiting time for scan / (O) patients accepting scan
B3	Increase in GP capacity increases the number of people scanned. The more patients are getting scanned the more pressure on GP capacity	GP capacity →(S) referral for scan → (S) patients accepting scan → (S) number of people scanned →(O) GP capacity
R3	The more GPs know the next steps after receiving abnormal CT of a patient the more GPs will refer for scan. The more people are being referred the clearer the next steps become	GP clarity on next steps after abnormal CT → (S) referral for scan → (S) patients accepting scan → (S) number of people scanned / (S) GP clarity on next steps after abnormal scan
B4	Increase in specialist capacity reduces the number of patients on the waiting list for treatment in timely manner. The more patients are being treated early the less specialist capacity available	Specialist capacity → (O) patients on waiting list for treatment → (O) patients connected with treatment in timely manner → (O) specialist capacity
B5	Increase in number of people scanned reduces healthcare capacity for scanning which increases subsequent waiting time for patients to receive a scan negatively impacting on patients' willingness to receive a scan	Number of people scanned →(O) healthcare capacity for scanning →(O) waiting time for scan → (O) patients accepting scan → (S) number of people scanned

(S) indicates that variables move in the same direction. (O) indicates that variables move in the opposite direction. LDCT, low-dose computed tomography; GP, general practitioner.

also be important from the participant perspective included lack of participant awareness around lung cancer and lung cancer screening, the geographic remoteness and distance to healthcare centres equipped with LDCT scanners and the participant's possibility to travel, and the associated direct and indirect costs (e.g., taking a day off work) of screening as reasons for participants to decline screening (34-37).

Primary care perspective

This view centred around GPs (primary care practitioners in Australia) who provide a unique lens through which to examine the factors influencing screening uptake. This perspective involves considerations, challenges, and decision-making processes that GPs encounter when determining whether to refer their patients for such screenings. Two main drivers were identified by stakeholders as likely to influence GPs' referral behaviours.

- Balancing loop B3 describes how the additional GP workload, coupled with an already high workload, particularly in rural or remote areas, presents a significant issue in the implementation of lung cancer screening. Stakeholders referred to the problem around availability of GPs in general, but also lack of time during standard consultations with patients to discuss the benefits and harms of screening for lung cancer. With a screening program in place, the number of referrals is likely to increase the need for GP capacity as patients would need to see the GP again after receiving a scan. Therefore, this balancing loop describes how additional capacity requirements for GPs could lead to fewer referrals for screening due to the increasing burden on the system. The lack of clinical time to address lung cancer screening in clinical practice and inform patients about benefits and risks of screening (e.g., exposure to radiation)

in the context of patient's medical history is also consistent with previous findings (38,39).

- Secondly, stakeholders indicated GPs are often unclear about the referral pathway after receiving an abnormal lung scan for a participant and the likelihood of a GP referring the participant for a scan would therefore depend on whether the GP has an understanding about the next referral steps. Currently, according to stakeholders, pathways for cancer care currently not only differ across states but also across hospitals within local jurisdictions. Reinforcing loop R3 describes that the more GPs refer the participants for screening, the more they will become familiar with the referral pathway and the more likely they will then refer for screening.

Other factors of relevance from the primary care perspective that were identified included the accuracy of primary records to inform screening eligibility such as availability of participant risk information, ease to identify participants, GP concerns relating to exposure to radiation, false-positive tests, management of incidental findings, and the invasive nature of the follow-up test for diagnosing the participant following a suspicious scan (39), which could potentially impact GP perceived benefit of a referral to screening. The stakeholder group also discussed the impact of healthcare provider stigma and nihilistic views on lung cancer treatment on lung cancer care, which were perspectives that were also evident in previous studies (32,39).

Health system perspective

From the health system perspective, which includes the dynamics of healthcare system capacity outside the primary care system, specialist availability, and macro-level factors such as resource allocation and infrastructure development, two main drivers were identified to likely impact the success of a lung cancer screening program.

- Balancing loop B4 describes how availability of specialist capacity influences how many participants are on the waiting list for treatment and how many are connected with treatment in timely manner. Stakeholder reported that the availability of specialists with expertise in lung cancer was currently an issue, with capacity likely to be further exacerbated with an increase in patient volume once a screening program is implemented. This is due to an expected increase in demand for specialists in radiology, pulmonary and particularly in thoracic surgery. A simulation model in Canada predicted a possible shortage of thoracic surgeons given the expected increase in operable early-stage lung cancers (40). Specialist capacity in a screening program will therefore likely impact on the timely treatment of patients and subsequent costs for the healthcare system. Even if some additional specialists can be hired to meet this need, there is an expected significant delay until optimal specialist capacity is achieved as it takes an extended period to train and hire such specialised medical staff.
- A second driver identified from the health system perspective identified by stakeholders related to healthcare capacity for scanning. Balancing loop B5 describes that with an increase in the number of people scanned in a screening program the more pressure is expected on healthcare capacity which leads to an increase in waiting times for participants to receive a scan if not enough capacity is available. Increase in waiting times for the participants will reduce their willingness to accept a scan, as noted before.

Other important factors that were identified by stakeholders related to the benefit-cost ratio of a screening program, which would be expected to increase if more patients are being treated at an earlier stage of lung cancer as opposed to costly late-stage treatments. With a possible increase in the overall benefit cost ratio, the Australian government might then be more inclined to further invest in the screening infrastructure. This may include increasing the number of facilities with LDCT scanners in rural and remote areas to increase capacity for scanning and thereby reducing participant waiting times to receive an appointment for a scan. Other investments could include reducing the threshold for screening (e.g., including other non-smoking related risk factors as well), providing investments in IT-infrastructure to support IT-interoperability across service contexts (currently a significant issue) (41), implementing public awareness campaigns to reduce stigma and to increase awareness of lung cancer and lung cancer screening, and developing nodule management standards to better educate GPs on the participant pathway.

Interdependencies between the participant, primary care and health system perspectives

The understand the interconnections between the three perspectives and the dynamics affecting lung cancer screening uptake, it is essential to examine how the feedback loops from each perspective influence other perspectives.

Table 3 Leverage points to intervene in a system

Perspective	Leverage point
Participant perspective	• Patient stigma influencing willingness to accept to receive a scan
Primary care perspective	• GP capacity to allow for more referrals for scans
	• GP capacity to increase patients' health literacy and their willingness to accept a scan
Health system perspective	• Specialist capacity to ensure patients is connected with treatment in timely manner
	• Healthcare capacity to reduce waiting times for a scan

GP, general practitioner.

The following examples demonstrate how the CLD reveals multiple connections between feedback loops:

- ❖ The participant perspective is influenced by interactions with primary care. The willingness of a patient to accept a scan is influenced by their health literacy which is directly impacted by the GP capacity to educate patients on the benefits of screening (B1).
- ❖ Participant and health system perspectives are linked through the waiting times for cans and the overall healthcare capacity for scanning. Delays in scanning due to increased demand in a screening program may make participants less likely to accept a scan (B5).

The primary care and the health system perspective are interconnected through the clarity on referral pathways for GPs and the timely connection of patients with treatment. An increase in detected early-stage lung cancers will also put capacity constraints on specialist capacity.

Discussion

This paper describes the development of a systems approach that aimed to capture the complexity of factors associated with uptake of a future lung cancer screening program in Australia. This study applies a system dynamics approach to lung cancer screening to understand these factors, their interconnections and dynamic behaviours, in the Australian context. Based on participatory workshops and evidence scans of the literature, the resulting CLD revealed critical perspectives influencing screening uptake. The participant perspective highlights factors such as fear of having lung cancer, shame and guilt associated with smoking, patient health literacy, and the impact of long waiting times for an appointment to receive a scan. GPs play an important role in the primary care perspective, with GP workload, uncertainty about the referral pathways, and concerns about radiation exposure, test invasiveness and false-positive tests affecting their decisions. From a health system perspective, specialist capacity, healthcare capacity for scanning, government investment and IT infrastructure collectively influence the screening program's success. The CLD further demonstrates that variables are either directly or indirectly connected with each other. If the CLD is a valid systems-level characterisation of Australian lung cancer screening, there are number of key leverage points to emerge that are of relevance in the design and implementation of a national screening program. Consideration of these key leverage points in the system can be used in subsequent stakeholder and policy discussion to ensure the uptake of screening among the eligible population (*Table 3*).

Leverage points in system dynamics refer to specific places within a complex system where a small change or intervention can lead to significant shifts in the system's behaviour. These critical points therefore represent opportunities to influence a system and achieve the desired outcomes. They are hierarchically categorised into twelve different points to intervene in a complex system, ranging from single variable changes with low impact to shifting paradigms with the highest level of impact (42). Rather than intervening system-wide, it is more beneficial to focus on the most relevant leverage points that drive the system behaviour. For example, strengthening the reinforcing feedback loops that promote positive change, and reducing the influence of balancing feedback loops that generate limitations to growth, are more powerful leverage points for achieving optimal system change than simply changing single parameters.

There were four key leverage points that emerged during the stakeholder discussions and that were included in the CLD. Firstly, from a participant perspective, stigma is a significant contributing factor to participants' reluctance to undergo screening. Therefore, efforts to reduce patient stigma are likely to drive positive change. Secondly, GP capacity was recognised as another crucial leverage point since it plays a role in two key limiting drivers (balancing feedback loops B1 and B3). Addressing GP capacity will impact how many participants are being referred for a scan, and also patients' health literacy and their willingness to accept a scan. Thirdly, specialist capacity is another key leverage point. Addressing this 'bottleneck' is crucial to ensuring timely patient connections with treatments,

reducing the costs associated with late-stage diagnoses and thereby enhancing the benefit-cost ratio of scanning. The fourth leverage point encompasses healthcare capacity for scanning. This factor contributes to shorter waiting times for participants receiving a scan, enhances participants' willingness to accept a scan, and facilitates early lung cancer detection.

In addition, it remains uncertain how participants will be identified and recruited into a lung cancer screening program in Australia. The process of implementation and the responsible parties for participant recruitment are not yet clearly defined. For instance, in the UK model, eligibility for screening is managed by a dedicated screening team (43). In the Australian context, it is evident that additional exploration and careful consideration are required in the planning and implementation of the program.

Strengths and limitations

The present study represents a unique attempt to delineate the complex web of system-level factors and their dynamic behaviours of an Australian lung cancer screening program by employing a system dynamics approach. This comprehensive CLD not only reveals the interconnectedness among variables but also delineates the participant, primary care, and health system perspectives. Consequently, the success of a lung cancer screening program depends on a holistic view and careful consideration of all three perspectives together. For instance, although increasing the number of participants undergoing screening through intensifying lung cancer screening campaigns may seem beneficial, neglecting to adequately enhance primary care and specialist capacity to accommodate the subsequent surge in positive findings after a scan can have unintended consequences.

This CLD developed in the current study can also be used to inform the development of a quantitative system dynamics model to simulate the interacting relationships identified in the CLD, as for other complex health outcomes like obesity, diabetes, suicide, osteoporosis, and COVD-19 (20-23). Qualitative findings from this study will be disseminated among policy stakeholders and decision makers to anticipate system-level barriers and facilitators of lung cancer screening uptake as the national program is implemented in mid-2025. Additionally, CLDs are often used to form an initial systems-level map that can be used as the basis for computational simulation (e.g., system dynamics models) for policy decision-support and prospective program evaluation. Computational simulation based on the CLD will allow for the quantification of the interaction between these different factors and perspectives, using routinely collected data, evidence from the literature, and expert opinion, which can be used to model 'what-if' intervention scenarios, individually and in combination, to inform the national program implementation and assess how they might impact the uptake of screening.

This study also has limitations. This study relies on the quality of stakeholder input and findings from qualitative research. The mix of stakeholders provided a particular perspective but may overlook other important perspectives. For example, while the consumer and clinical stakeholders were well represented there was only a single GP providing perspectives on the management of lung cancer cases and experiences with referrals for treatment. Existing evidence used to support stakeholder comments/inputs was also predominantly from other countries and findings may not be replicable to the Australian context. Additionally, while Australia is not mandating shared-decision making as part of lung cancer screening at this stage, the need for the further delineation of the complexities relating to individual patient decision-making, including patient health literacy, help-seeking behaviour, and feelings of guilt and shame, is a limitation in this CLD. The CLD also relates to the Australian population as a whole, and does not account for subpopulations such as First Nations people where smoking history and lung cancer incidence and mortality are historically higher (4,44). This population would require a different process for capturing system-level perspectives of lung cancer screening.

Conclusions

This study explored the factors that likely influence the uptake of a future lung cancer screening program in the Australian context through a participatory system dynamics approach. The CLD developed identified the importance of the relationships of variables across the participant, primary care, and health system perspectives. This CLD may be used to support decision-makers gain a better understanding of system-level influences on lung cancer screening uptake. This CLD can also subsequently be used to inform the development of a quantitative system dynamics model to simulate the interacting relationships identified in the CLD and test different "what-if" intervention scenarios and how they may impact the uptake of screening under different health policy scenarios. This would further help in the

design of an effective lung cancer screening program before implementation in the real world.

Acknowledgments

Parts of this paper were presented at the 2023 International System Dynamics Conference. We thank the stakeholders, clinicians, policy makers, and researchers who contributed to the workshops that informed the development of the systems perspective of lung cancer screening.
Funding: None.

Footnote

Peer Review File: Available at https://tlcr.amegroups.com/article/view/10.21037/tlcr-24-425/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tlcr.amegroups.com/article/view/10.21037/tlcr-24-425/coif). E.S. received speaker honoraria from Astra Zeneca, Merck Sharp & Dohme and the Limbic; support for attending meetings and travel from Astra Zeneca LOBES 2022; received *ad hoc* advisory board payment from Bristol Myers Squibb 2022. E.S. is the Deputy Board Chair Thoracic Oncology Group of Australasia (unpaid) and also the Editor-in-chief for the JTO CRR. F.B. reports honoraria for educational talks to primary care and secondary care specialists from Boehringer Ingelheim and Astra Zeneca. N.N. reports research funding from a Medical Research Council Clinical Academic Research Partnership, CRUK, NIHR, Horizon Europe and UKRI (Grant number MR/T02481X/1); reports honoraria for non-promotional educational talks or advisory boards from Astra Zeneca, Bristol Myers Squibb, Fujifilm, Intuitive, Janssen, Lilly, Merck Sharp & Dohme, Olympus, Sanofi and Roche; he also received support for attending meetings from Astra Zeneca, Fujifilm, Intuitive, Merck Sharp & Dohme and Olympus. He also reports consulting fees from Amgen, Astra Zeneca, Boehringer Ingelheim, Bristol Myers Squibb, Daiichi Sankyo, EQRx, Fujifilm, Guardant Health, Intuitive, Janssen, Lilly, Merck Sharp & Dohme, Olympus, and Roche and has leadership roles for the British Thoracic Oncology Group, UK Lung Cancer Coalition and National Lung Cancer Audit. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Cite this article as: Marjanovic S, Page A, Stone E, Currie DJ, Rankin NM, Myers R, Brims F, Navani N, McBride KA. Systems mapping: a novel approach to national lung cancer screening implementation in Australia. Transl Lung Cancer Res 2024;13(10):2466-2478. doi: 10.21037/tlcr-24-425