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Systematic Analysis of Medication Errors in an Indian Context Using the Swiss Cheese Model

Vrashal Verma[a], Dipti Singh[b], Manish Kumar Asthana[a,b]*

[a]*Department of Design, Indian Institute of Technology Roorkee, Roorkee, India.*
[b]*Department of Humanities and Social Sciences, Indian Institute of Technology Roorkee, Roorkee, India.*

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A B S T R A C T

In the past two decades, medication errors have grown in India. During recent times, the work on medication error in the Indian context, focusing on the Swiss cheese model, is limited. Medication error interventions should be explored using the systems thinking approach. The systems thinking approach might help us to understand its necessity as a precautionary and preventive measure for medication errors. To perform a systematic analysis of medication error in the Indian healthcare setting using the Swiss-cheese Model. To understand the holistic thought in the medication errors system, systems thinking is used. We analyzed the outcomes of the system mapping with the help of the Swiss cheese model. The current work is made with the latest paper on medication errors from an Indian perspective. Common errors address interconnections and dependencies of medication errors from the systems perspective in the phases of medication errors. The results highlight the importance of the Swiss cheese model in the prevention of medication errors. Before the implementation of the causal loop diagram, consideration of the layer model of the Swiss cheese model was certainly implemented. By applying the Swiss cheese model, the study demonstrates the criticality of multiple system layers where errors can occur. The dynamic behavior of the medication error system is understood with the cluster diagram and causal loop diagram. Medication error rate and medication error capacity are critical factors in system behavior. The Swiss-cheese model predicts the critical factors of the system's behavior and provides preventive and precautionary measures in detail. The understanding of these attributes helps in the identification of medication errors in the healthcare system. Cross-functional findings of the theories, models, and principles of the medication error systems thinking can be utilized for understanding the holistic view.

Keywords

Medication error, Swiss cheese model, Systems Thinking, Causal loop diagram.

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****Corresponding author***
Email: m.asthana@hs.iitr.ac.in

1. Introduction

An unchanging theme of the patient-centered care approach is emerging in the healthcare systems. In an applied healthcare setting, the focus on medical error management has intensified, due to the prevalence of medical errors causing deaths, and rising cases of misdiagnosis (Keebler et al., 2022). Medication errors can be defined and characterized as the prescribing (dosage and measurement of dosage), supply, product labeling, administration, and education (Chanakit, 2013; Cohen, 2007). These errors could be linked to medication mismanagement and confusion arising from medicine naming and labelling (Brunetti and Suh, 2012). Furthermore, these prescription errors can be categorized into two diverse forms: delivered drug, which is administered to the patient, and an intended drug, which is related to the prescriber's decision (Basco et al., 2016). This categorization becomes vital in high-risk populations like the elderly, who need assistance in critical care and are more vulnerable to medication errors.

Different models and approaches have been proposed to address healthcare error-related issues. These models could be categorized as either linear or causal, based on their underlying framework. This framework defines how the underlying variables and factors interact with each other and lead to the outcomes. The systems thinking, non-linear approach provides a lens to reframe the conversations of seeing the "whole" system, not "silos" in isolation. The designers face a major challenge in changes in the system dynamics models of errors and management in real-time events (Clarkson et al., 2004; Wieman and Wieman, 2004). This approach plays a vital role in identifying vulnerabilities, particularly those arising at various levels like prescribing, dispensing, and administration (Bhowmick et al., 2020). The whole central tenet of systems thinking involves causal diagramming and policy-oriented computer simulation models (Homer and Hirsch, 2006). Despite its effectiveness, this approach has been underutilized in Indian medication industry, where anesthesia-related major concerning errors have been reported (Dave et al., 2022). Therefore, integrating systems thinking in healthcare is important for medication error flows, such as medicine naming, labeling, and other details.

System dynamics approach can further deepen insight into medication errors by uncovering the underlying causes of the errors. It enables designers to visualize and address the specific vulnerabilities, such as look-alike and sound-alike (LASA) errors, by identifying their antecedents and mapping their flow in the healthcare system.

On the contrary, the Swiss Cheese Model (SCM) is a way where the thinking and process are inappropriate for the context or issue explored (Chuang et al., 2008). Various systems thinking tools are used to understand the occurrences of the problems of likely and unlikely events in the medical error realm (Anderson and Johnson, 1997). Medication error in the Indian context is justified with confusion related to the naming of medicines. Medication errors due to look-alike and sound-alike (LASA) medicines are very common in medicine (Johnson et al., 2020). SCM plays a crucial role in eliminating label comprehension-related errors (Hussein, 2018). The labeling and design of the labels play a vital role in the communication of information to the patients, including the dosage, direction, and precautions. Any medication lapses in the medical scenario can cause an Adverse Drug Event (ADE), which apparently leads to a medical error. The vulnerabilities in the medical labeling system and the errors caused by various factors can be interlinked with the cause-and-effect relationship between the factors (Reason, 1990). Some medical errors are inevitable, even if the medical ecosystem is performed with validation and perfection (Spath, 2011). Adopting the systems thinking approach in medication errors improves patient safety (Fialová and Onder, 2009).

The occurrence of medication errors is directly proportional to the quantity of information present on the labels (Law and Zargarzadeh, 2010). The LASA name pair list is used to inform healthcare professionals about the high probability of occurrences of medication errors (Cohen, 2007; Wong, 2016). Medication errors can be defined and characterized as the prescribing (dosage and measurement of dosage), supply, product labeling, administration, and education (Chanakit, 2013; Cohen, 2007). The systems thinking approach can further help in identifying the causal factors leading to LASA errors and design solutions to address the underlying system vulnerabilities (Schnoor et al., 2015). The elements of the SCM consist of 5 layers of failure. These layers are explained in detail in Figure 1.

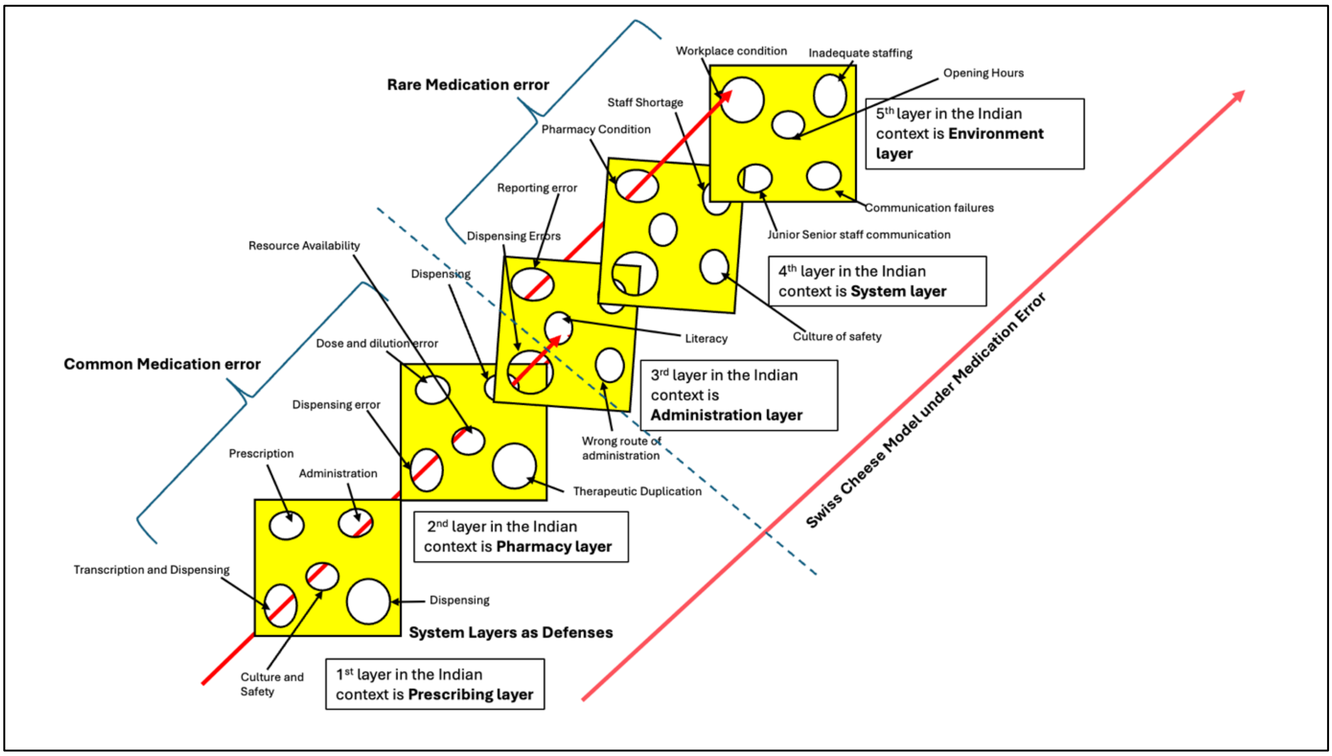

Figure 1. Case-specific demonstration of the swiss cheese model of medication error. Adopted from Reason's swiss cheese model, published in 2000

The critical information about the medicine is communicated through the prescription labels, such as medication name, dosage, directions, and precautions (Davis et al., 2006) (Institute of Medicine, 2007). Comprehending the drug indication using labeling design also involves the medicine container and the user approach in the usage of the reason for use (RFU) (Hussein, 2018). The RFU remains on the label for the entire treatment of the patients. The treatments totally depend on the type of usage during the intake of medicines. Therefore, it shows the limitations in the amount of information deployed for the services by the healthcare givers to avoid medication errors and ensure safe medication use (Institute of Medicine, 2007).

Despite the efforts of labeling the medication details, many independent or dependent older population faces label comprehension-related challenges (Szczepura et al., 2011). In the Indian context, related studies have revealed that only one in eight patients correctly comprehend medication-related information (Persell et al., 2004). Similarly, other Indian studies highlighted the alarming situation that the patient's perception of medical prescriptions is dependent on the healthcare giver's knowledge (Roy et al., 2020).

Systems thinking and causal loop diagrams are quite familiar in the healthcare domain. From an application perspective, the causal loop diagram is utilized as an effective tool in the systems thinking approach. The Swiss cheese model has proven to be appropriate for both low-and middle-income countries (Dubb et al., 2022). To be impactful, systems thinking must be planned and implemented based on fields such as quality improvement, implementation science, and operational research (Tetuan et al., 2017). The need for the systems approach is highlighted when the medication error is analyzed from the linear approach, such as root cause analysis (Peerally et al., 2017). In comparison to the systems thinking tools in the Indian context, the Swiss cheese model is quite appropriate for the system thinker to encapsulate the medication error problems.

Complementing these system-based approaches are principles from Human Factors and Engineering (HFE) and work system design. These designs interlink macro-ergonomics and sociotechnical system design to build a more resilient healthcare environment. Furthermore, the patient and healthcare interaction could be enhanced using these effective system interventions (Carayon, 2012).

Central to the development of Human Factors and Engineering (HFE) are three major factors 1) Joint design, 2) Humanized task approach, and 3) Organization's socio-technical characteristics (Carayon, 2012). Joint design refers to the amalgamation of personnel subsystems as well as the technological subsystems to generate a human-centered approach in medical system design. For the development of the design process, joint design criteria will enable an inclusive employee participation (Leape, 1997). Humanized task approach refers to the initiation of a functional model that demands a function and task allocation process. This process checks whether there is a necessity in the presence of a human to perform such a task. Unlike the joint design approach, here exists a system consideration of professional requirements and cultural psychosocial characteristics of the personnel subsystem (Carayon, 2012). Organization's sociotechnical characteristics refer to the integration of culture into the work system design (Carayon, 2012).

In view of the above deliberations, the present article explores a comparison between SCM and non-linear approaches to address medicine-related errors in the Indian context. Additionally, the paper incorporates Human Factors Engineering to evaluate how each framework responds to vulnerabilities related to labeling design, Reason for Use (RFU) integration, and Look-Alike Sound-Alike (LASA) drug errors (Hussein, 2018). Overall, the current paper intends to perform a systematic analysis of medication error in an Indian context using the Swiss-Cheese model, which may highlight some context-specific strategies.

2. Medication and medication error

A system can be understood as a pattern of interconnections between processes and elements.

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The Institute of Safe Medication Practice (ISMP) has defined 10 key system elements that significantly influence medicine use (Cohen, 2007). Therefore, it is important to approach patient information from a systems perspective (Cohen, 2007). According to the ISMP, some important variables in systems thinking are patient information, communication, drug names, labels, and packages. Among these variables, labeling plays a vital role in communication through RFU, which is a significant contributor to the proper medical care (Hussein, 2018). The systems thinking approach highlights the application of RFU depending on various interconnected factors.

The elderly population, whether dependent or independent, experiences several health-related challenges requiring multiple medications. This highlights the necessity of redesigning the healthcare delivery system that substantially provides the essence of the right information on a global scale (Crane and Crane, 2006; Vernaz, et al., 2020). The complex system interventions require various stakeholders and system variables to play a role in the context of medication errors and drug replacement. The agents are mentioned as people who have diverse roles in the complex environment, like the outpatients in the older population in Indian settings. The agent, involved in the subsystem and system within the environment, requires a patient-centered approach. Redesigning this system will require aligning communication with its meaningful interpretation.

Traditional cause-and-effect diagrams suggest that the complexity of the system has increased over time (Underwood and Waterson, 2014). The analysis of medication errors by the Swiss Cheese Model (SCM) is widely used in healthcare (Underwood and Waterson, 2014). SCM consists of defensive layers to prevent the medical hazard (Guise and Mladenovic, 2013). This model is criticized as simplified method of understanding errors (Dekker, 2007). Therefore, in order to study the fallible decisions created by the designers at a decision-making level, system design approaches should be implemented.

This model has a linear approach, which restricts the system thinkers from applying the interrelations between the model for a better understanding (Samaranayake and Cheung, 2013). The defensive layers in this specific model are elementary and implicit for the slices and holes (as shown in Figure 1) (Reason, 2000). The Institute of Medicine (IOM) has articulated a drawback of the SCM, that it demands a halt to the occurrence of medication errors due to the holes in the system lineup (Guise and Mladenovic, 2013). Unlike systems thinking, which explains the role of culture, policies, and other individual components of the healthcare

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environment, SCM struggles to explain these factors. Medication errors are layer-wise in nature. In order to resolve the complex medication error, an SCM approach is required (Banja, 2004).

Error propagation in the healthcare domain is constantly changing and dynamic in nature. The healthcare industry needs a few trained system interventions to help in understanding the patient-physician interactions (Oxman, 2023).

3. Indian context

Over the past 25 years, Indian research has highlighted three key fundamentals covering medicinal errors: communication skills, communication effectiveness, and error reduction. Through word frequency analysis in published studies, it illuminates factors leading to communication-related errors. These include poor supervision (Rani, 2020) attitudes and beliefs (Gautam, 2013), and issues related to labeling (Vaidya and Joshi, 2023) (see figure 2).

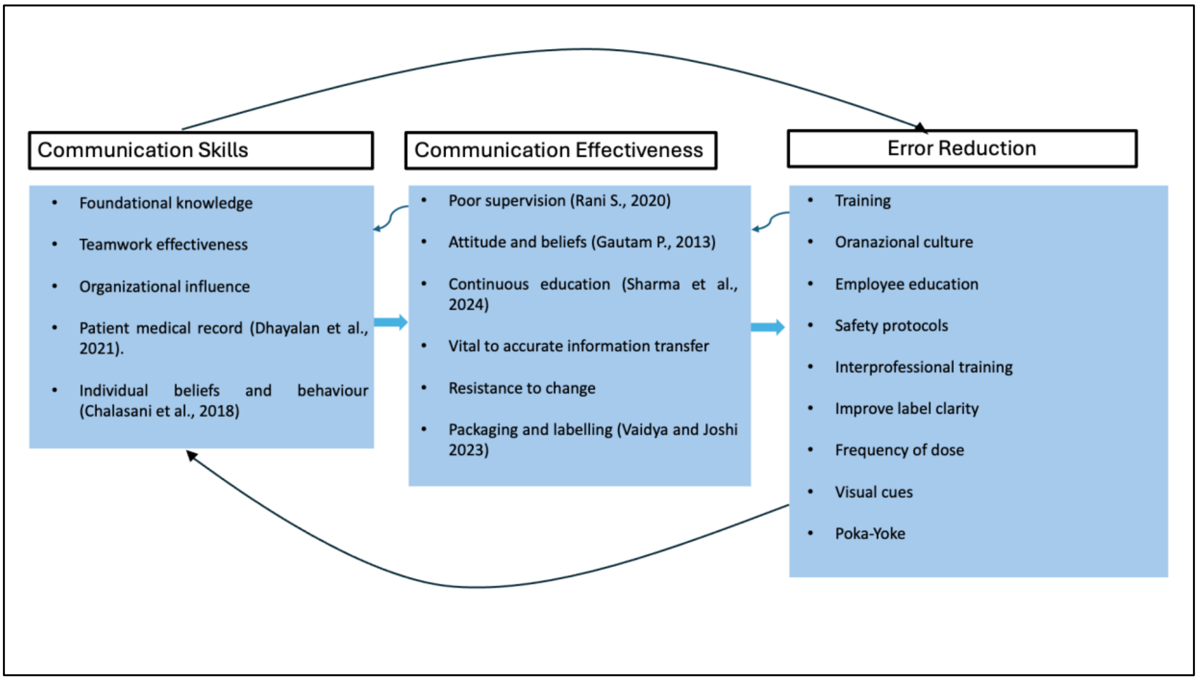

Figure 2. The interaction of the three major headings found in the word cloud of the frequency of keywords in papers

The healthcare in the Indian context takes a system-oriented approach by emphasizing the system failure rather than the human. The Quality Improvement (QI) of healthcare needs to consider the People, System, Design, and Risk (PSDR) approach to study the medication error problem from a systems thinking lens (Chada, 2022). The system evaluation requires the evaluation of skills, culture, and safety management. The sharp end in the Swiss cheese model helps in reducing the risk proactively (Cross, 2018). The Indian medical system needs to educate the healthcare professionals and patients to curb medication errors (Sharma et al., 2016).

4. Research methodology

Several systems thinking tools are available in medication error analysis. In this article, we are using the Setting, Plan, Impact, Critical event, Decision (SPICE) methodology to mark the research gaps and system lacunas. Setting- Medication errors are reported in the Indian scenario using tools such as Medication Error Reporting Program, MEDMARX, Drug-Drug Interaction Program, such as Drug Interaction Checker for Prescription (DICP) (Kulkarni et al., 2013; Zirpe et al., 2020). Plan- Digitalization efforts to check the medication errors, but the problem persists in the medication system. To address the complex problem, a mixed approach of systems thinking tools is used. These tools are the Swiss cheese model and the causal loop diagram. Impact-For the right impact, focusing on the linear approach and layered approach, such as the Swiss cheese model, is needed (Karmakar and Das, 2025). A causal loop diagram addresses the complex recurring nature of the medication error. Critical- The medication error propagation and patient harm are critical areas of Intervention. Decision- For decision-making, the layered approach of the Swiss cheese model is utilized, which addresses the holes and problems at the layer level and later propagates to the system level and causes patient harm in the end.

4.1. Fragments of SCM

Introduction to the SCM for medication errors in the Indian context is important because of the various communication factors, such as prescribing, pharmacy, administration, system, and environment. The SCM perspective of medication error in the Indian context is important because of the causal factors. Hence, emphasis should be placed on understanding the application of systems thinking in the healthcare system of primary caregivers (Rodziewicz et al., 2024). Investigating the contributing factors of patient safety and medication error is important. These factors are environment, workplace, visual design of labeling, and medication error rate (Guise and Mladenovic, 2013). These factors are connected to the SCM of medication error. The factors of medication errors are environment, workplace, visual design, and medication error under the head of communication skills, communication effectiveness, and error reduction.

This common repetitive pattern emerged from the problem (Monat and Gannon, 2023). Such issues include error prevention, mitigating adverse effects, information on the label, and

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cognitive load (Nolan, 2000). A systems-level approach provides valuable insights towards understanding multi-faceted healthcare factors in medication errors (Maidment et al., 2006). Better health at low cost can be achieved with systems knowledge in healthcare (National Academies of Sciences, Engineering, and Medicine [U.S.], 2018). The categorization of medication errors with respect to system behaviors is dynamic and constantly changing (Anderson and Webster, 2001). According to the Institute of Medicine (IOM) report 2016, safety programs are being launched to prevent and mitigate adverse drug effects (Johnson et al., 2020). SCM is not enough to answer the medication error factors and interrelationships of the causes and effects of the medication factors (Buist and Middleton, 2016). The barriers that exist in the SCM model are not random. The holes and layers in the SCM model for medication error are dependent on the Indian context of medical practitioners. Medical practitioners in the Indian context are facing the challenges of communication. These factors are interconnected and must be addressed by systems thinking (Kohn et al., 2000). The SCM model limitations can be explained by limitations when applied to medication error and the healthcare system. SCM is a relatively simplistic approach that fails to adequately capture the complex interrelation between the individual and the hospital system (Buist and Middleton, 2016).

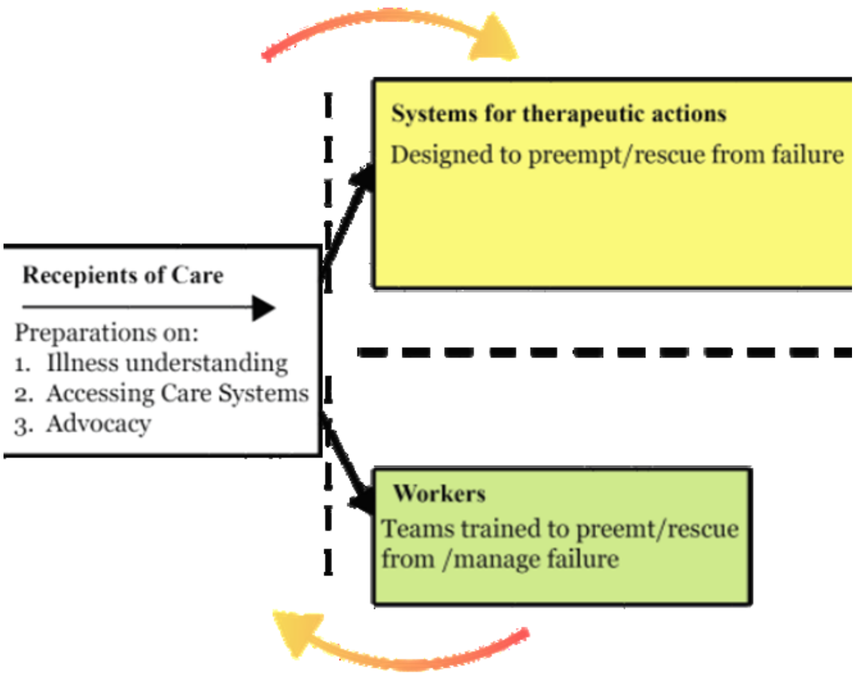

Figure 3. Adopted from the patient safety system model (Johnson et al., 2020)

The model consists of feedback loops to monitor performance. The patient safety model explains the interactive elements, such as Patients (the recipients of care) and healthcare workers (the primary caregivers) (Johnson and Anderson, 2017). The dotted line represents the permeability between the patient safety system (see figure 3) and the stakeholders. Continuous quality improvement (CQI) in healthcare connects the patients, plant, processes, and policy to facilitate safer healthcare (Johnson et al., 2020). These interlinks help to understand patient safety as a system (Johnson and Anderson, 2017). Workers such as the high-functioning teams with adequate knowledge of medication, healthcare, and technology need to understand the non-technical competencies such as care, empathy, and inclusivity.

4.2. SCM Layers

The SCM in the medication error of the healthcare system, where the medication error of look-alike and sound-alike names is the reservoir of the problem (Koelling and Schwandt, 2005). The observation of medication error from a system's perspective gives the behavior of the system over time. Layers in SCM, medication error failures, socio-technical factors, and adaptation over time are studied by a layered analysis of error prevention (Leveson, 2004).

SCM is useful in the analysis of design problems where interrelationships between causal factors are required. The interrelationship between the causal factors of the medication error system needs a holistic understanding from a systems perspective.

4.3. SCM and medication error

Medication error systems go beyond the organizations and create their own characteristics overall time (Kapp et al., 2017). The system may collapse due to the following medication error factors of look-alike and sound-alike medicine names. Therefore, the system interventions in the area of medication errors are relevant (Isherwood and Waterson, 2021). The results identified by the SCM can be better analyzed using the system dynamics.

The exponential decay observed here is a common occurrence in various fields, such as population dynamics and radioactive decay. Here, the pattern of the behavior of the Medication error capacity shows the characteristic pattern of rapid initial decline followed by a slowing rate of change. The logarithmic curve reveals the constant decline rate, which is important for understanding the hidden pattern of system behavior. This metric indicates the system’s resilience and can become informative in the analysis of the complex, time-dependent phenomena (Badiru and Ijaduola, 2009).

Explanation of factors in SCM starts with education on medication errors. In India, this is crucial in the field of medication error. The application of medication errors is in the label design of the medicine, the medical education cost on patient safety, quality of care, and healthcare costs. Medical education in the causal loop diagram can help in the causality of the medication label information. The foundational knowledge of medical anatomy, physiology, and product inspection can be studied using the cluster diagram from an educational perspective, as shown in SCM, which helps the designers analyze the holes in the system and how they align with the weaknesses in the system. Medication errors occur at multiple levels, which is highlighted in the SCM of the medication errors. These defenses, as layers, act as systems, and holes represent the weaknesses.

In the education domain of medication, errors are foundational knowledge, skill development, and competency. Cultural competence, teamwork, communication, and patient education are important for medication errors from the medication perspective. Simulation of medication errors is concerned with the training and education of the nursing staff.

4.4. SCM and holes

In the Indian context, the medicine used depends on the infrastructure, hospital and pharmaceutical infrastructure, medical label, and skills of the healthcare workers.

Culture plays a competent role compared to medical education in label design. The medical knowledge of the error possibility in the label design propagates with errors in the medication error system.

Strategically, the system-level interventions of the Swiss cheese model consist of communication skills, communication effectiveness, and error reduction in the SCM model of the medication error from an Indian perspective.

SCM and layer-wise attributes can be broken into the model's function, task, and description. The functional aspects of the system include risk management, Error prevention, and Quality improvement (Correia et al., 2023).

4.5. The system

SCM and application to the Medication error requires the development of a new approach in SCM for the medication error (Keating et al., 2021).

1. Using systems thinking to provide layer-wise analysis of the medication error and error propagation. The first layer consists of the holes that explain and represent the error related to the transcription, culture, prescription, dispensing, and administration (see figure 2). As illustrated by Sameera et al. (2021), the fundamental issues of the medication error from

the SCM perspective are errors related to transcription, culture, prescription, dispensing, and administration.
2. The second layer of SCM, which is the pharmacy layer, comprises the medication errors related to the employees in the pharmacy. These medication errors arise from the latent and active errors (Sameera et al., 2021). These active errors are changing as per the Indian context, which is the second layer. In the Indian context, the pharmacy layer is the biggest source of medication error related to communication-related errors. In such scenarios, dispensing errors, duplication, dose-dilution errors, and communication errors occur.
3. The next layer explains that the SCM errors arise due to the following causes: communication, inadequate staffing, defective equipment, and reporting literacy of the pharmacy professional involved (Alharbi et al., 2018; Tariq et al., 2024).
4. The subsequent layers, i.e., the third layer, represent the healthcare organizations and medication management errors from the administration level. Elaborately, these errors reduce the quality of care, increasing the risk of patient harm and poor reporting systems. Drug labeling, shortage of storage facilities, and lack of medical education are factors in this layer (Sewal et al., 2014).
5. The system layer and its failure occur due to uneven distribution of healthcare facilities, pharmacy infrastructure lacking in resources, untrained pharmacies, unmet quality standards, and medication handling (Mitra and Basu, 2020).
6. The environmental layer in SCM for Indian medication error stands for the noise, interruptions in the pharmacy, poor pharmacy reporting system, language barriers, and hierarchy of reporting in the medication error reporting system (Mitra and Basu, 2020), see Table 1.

Table 1. Perspective on indian medication error table on the Swiss cheese model and system dynamics in relation to medication errors

Characteristic	Swiss Cheese Model	Systems Thinking
Focus	Identification of system-level defenses and their weakness.	Understanding the complex, dynamic, and interconnected factors that contribute to medication errors.
Strength	Proposes a clear and intuitive framework for understanding error causation.	SD provides a clear and intuitive framework for understanding error causation.
Limitation	Simplify the complexity of the problem.	Challenging in terms of implementation due to the need for in-depth analysis and stock and flow modeling.
Application	Identification of multiple factors that lead to patient harm, medication errors, and holes in each layer.	Medication arises from interactions between various system components and elements such as communication, environment, policies, and human factors.
Key components	Organizational influence on the medication system and problems and errors in the form of holes. Unsafe supervision, unsafe acts and and organizational influence.	Stocks (medication errors), Flows(medication error rate), and feedback loops (e.g., monitoring and adjustment).

5. Results

5.1. System dynamics

The findings focus on the need for identification of the healthcare system factors of the look-alike labeling and naming medicines (To Err Is Human: Building a Safer Health System, 2000). These factors emphasize the identification of system factors from individual factors. Medication

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errors with confusing drug names (LASA) are caused by the weak medical system design and human error-related factors (Billstein-Leber et al., 2018; Cohen, 2017). Systems thinking helps to understand the healthcare system and medication errors in a more holistic manner (Kapp et al., 2017). These systems go beyond the organizations; they have their own characteristics over time (Kapp et al., 2017). Therefore, the system interventions in the area of medication errors are relevant (Isherwood and Waterson, 2021).

The results identified by the SCM can be better analyzed using the system dynamics. The results are enriched with the system dynamics. Healthcare organizations can better analyze the interrelated factors related to medication errors (Zanker et al., 2021).

5.2. Causal loop diagram

Causal loop diagrams are among the most used and valuable health research methods (Uleman et al., 2021). In the center of the causal loop diagram (CLD) lie the nodes and connections (Barbrook-Johnson and Penn, 2022). The positive connections show one factor increasing with another factor, a reinforced loop. Causal loop diagrams are the precursors to the system dynamics models, for example, stock and flow diagrams. To understand and classify causal factors linked to medication errors, product managers and designers should understand system dynamics. System changes can be defined and predicted by CLD (see Figure 4).

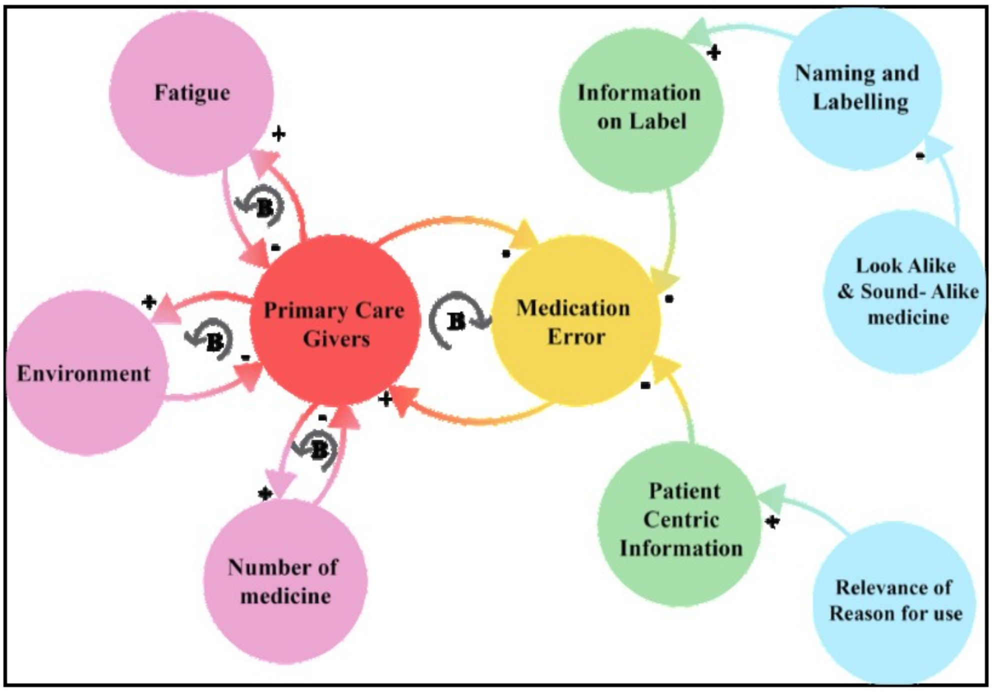

Figure 4. Causal loop diagram for medication errors (B Balancing loop)

Avoiding blaming individuals for adverse events and medication errors simplifies the system factors (Smetzer et al., 2010). Hence, while designing a new system for the medication application, it is important to consider the SD and SCM recommendations on medication errors. The existing products should incorporate the system dynamics recommendations for better medication error reporting. System dynamics and the SCM can be applied in the error-monitoring techniques for the quality improvement of existing healthcare systems (Barker, 1995). Exploring the mental model provides details on medication errors. The mental modeling represents the cognitive detailing of the medication error (McDowell et al., 2009). Systems thinking is the foundation of the medical system world.

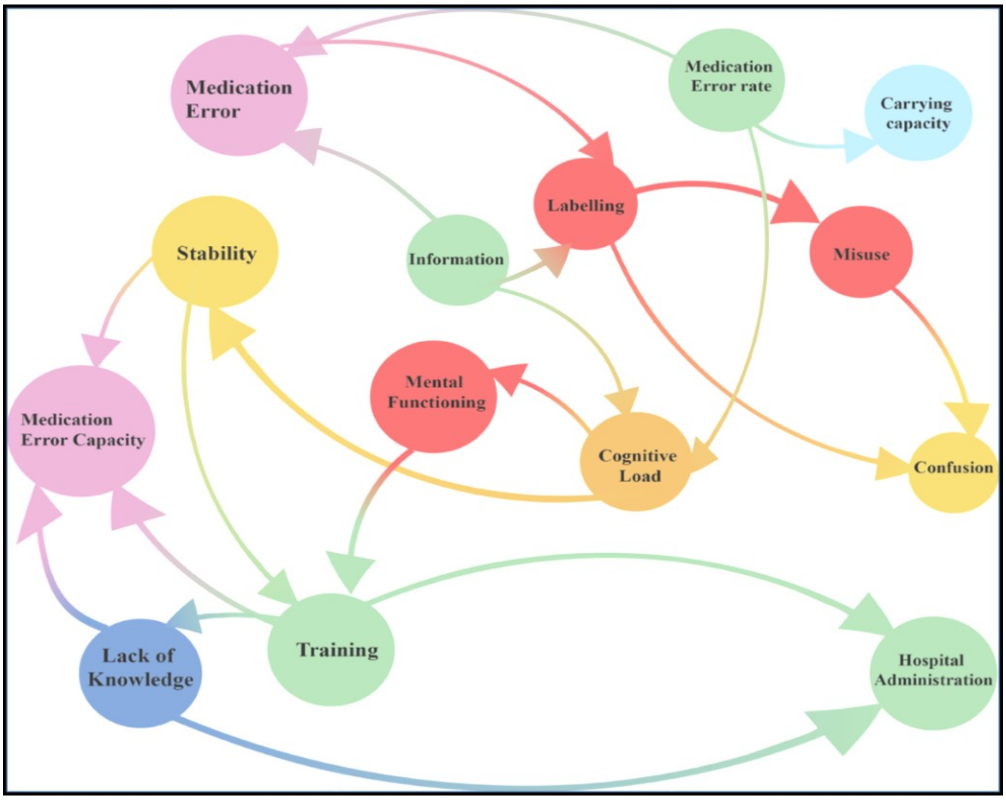

Figure 5. *Cluster diagram*

Such outcomes could help designers deliver the right amount of information on the labeling. System dynamics certainly aids product managers in understanding and identifying medication error patterns. The model shall help in predicting meaningful steps to better understand and curb medication errors.

The CLD illustrated in Figure 4 shows two clusters: the primary caregivers and medication errors. The primary caregivers' challenges are of the human factors, such as fatigue, environment, and the number of medicines to be given to the patient. On the contrary, the medication error cluster has information on the label that shows the negative (inverse)

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relationship with the medication error. The patient-centric information also shows a negative relation with medication error, meaning the better the patient-centric information, the less the medication error (see Figure 4). Four reinforced loops exist in the CLD. Loop 1, which is between the fatigue and primary care givers, has a negative relationship with each other (balancing loop). Loop 2 is between the environment and primary caregivers, which shows that they have a negative relationship with each other (balancing loop). Loop 3 between the number of medicines and primary caregivers, which is balancing in nature.

The Second cluster of the causal loop diagram shows a negative relationship with the first cluster of the primary caregivers (balancing loop). Within the second cluster, important factors such as information on the label and patient-centric information have a negative relationship with each other (balancing loop). On the contrary, the naming and labeling hold a positive relationship, because the more the naming and labeling, the more information is on the medicine label.

The process of creating the CLD diagram starts with defining the cluster diagram. The cluster diagram helps in revealing similar groups (see Figure 5). A cluster diagram also simplifies the CLD and elaborates the causal relations between the interacting groups. Further, the cluster diagram has nodes that help in the creation of the CLD and loops. Contrary to the CLD cluster diagram, it does not have a polarity relation; it represents the relation of connectedness of various factors in the medication error system (or any system).

The findings here specify the need for the Swiss cheese model in understanding medication errors. The layered approach of the Swiss cheese model helps in finding the various holes or error-prone possibilities in the medication system. Our conceptualization is based on the James model (2000) of the Swiss cheese model for error propagation (see Figure 1). This model is modified as per the Indian medication errors. This model guides the reader on how multiple holes and errors align to cause patient harm. The layered approach in the Swiss cheese model for medication error is Layer-1.) prescription layer, the problem starts from transcribing errors, Layer-2.) pharmacy layer, where the error of wrong medicine is given to the patient, Layer-3.) administration layer, where the wrong route to administration and literacy is critical, Layer-4.) system layer, the role of culture of safety and staff shortages, Layer-5.) Lastly, the workplace environment, the workplace condition, inadequate staffing, and staff communication are addressed. The sequential explanation of the Swiss cheese model is important to communicate with the stakeholders. The decision-making in medication error is further plotted based on the key factors, which are highlighted in the cluster diagram (see Figure 5). Contrary to the standard procedure of creating the cluster diagram from participants and stakeholders, this diagram is created based on literature data, such as Patel et al. (2016).

6. Discussion and scope of this review

The current paper examines a comparison between SCM and non-linear approaches to address medicine-related errors in the Indian healthcare context. We used the SCM to analyze the temporal, dynamic, and causal perspectives of trends and patterns in medication error. Over the last 9 years (2016-2025), medication error-related perspectives were accumulated. The layers of the Swiss cheese model and the causal loop diagrams were constructed using the data from Patel et al. (2016), where they researched the cases of medication error in the western state of Gujarat, India. The study highlighted the types of medication errors in various stages of medication treatment. Factors related to the medication label and associated factors are derived from the context of the study done by (Patel et al., 2002). This study emphasizes the role of medicine labeling in preventing medication errors. As stated by researchers in the Indian context, medication errors are like an iceberg because healthcare workers see only a fraction of medication errors (Ambwani et al., 2019). As shown in Figure 1, the majority of medication errors are in prescribing (layer 1 SCM), documentation (layer 2 of SCM), administration (layer 3), and dispensing (layer 4) (Parthasarathi et al., 2021).

Previous studies utilizing SCM have highlighted the following factors: (a) Medication error in India, (b) Private services, (c) Resource Availability, (d) Facilities, (e) Public Sector, (f) Public education, (g) Reporting, (h) Pharmacy system.

The factors to be addressed in the medication error system are causal in nature. These factors need systemic intervention to address the rate of change in medication errors. Systems thinking has various methods to bring a collective change in the medication error problem. One such approach is SCM, which is more comprehensive in addressing the wide range of contributing factors that are barriers to the reduction of medication errors.

Institutional support from bodies like IOM and India's Drug Technical Advisory Board (DTAB) could assist in establishing guidelines and strategies to curb medication errors. These errors, along with adverse drug events, are the areas where systemic failure exists Vernaz, et al., 2020). Adverse drug events and medication errors are the areas where existing systems have failure problems (Vernaz et al., 2020) even though the new medication policy and medication regimen are not considered for the medication error analysis the rise in complicated medication practices, more effective ways to curb medication errors and guarantee medical safety for individuals should be focused upon. Examples in the Indian context showed how the system tools, along with SCM, helped in reducing the medication error (Paul et al., 2023). The system dynamics model offers valuable insights into medication errors associated with look-alike and sound-alike over-the-counter medicines. Employing system modeling and the iceberg model facilitates the analysis of emerging and complex medication-related issues.

Solutions should be developed based on effective interception strategies and policies that regulate and monitor medication labeling and naming information (see Table 2).

Table 2. Systems thinking skills, Source: Modified from (Adam and De Savigny, 2012)

Swiss cheese model (A classical approach)	System dynamics (Systems thinking approach)
Linear Thinking	**Dynamic Thinking**
Focus on the linear chain of events	Framing the problem with respect to behavior over time
Events as a cause of thinking	**Systems as a cause of thinking**
Viewing the error outcomes the cause of chain process	Thinking system as the cause of events
Layer-by-layer thinking	**Forest thinking**
SCM gives a prediction in terms of layers of the defence mechanism	Thinking of the interlinking of the problems as the cause of the problem
Has application in healthcare and aviation	**Has application in business, ecology, and social systems**
Focuses on error and adverse event	**Focuses on the mental models, mission, and vision**
Straight line thinking	**Loop thinking**
A linear approach, assuming causality moves in a linear direction	The feedback loops exist for the system behavior to be updated over time

Medication error documentation and previous studies of root cause analysis highlighted the need to shift away from individual blame. Alternatively, underlying system-level factors should be explored. A combined approach to address medication error from person-centered and system-centered is needed to minimize administration errors (Jones, 2009).

The limitations of knowing the medication errors in detail require a field survey to gather data on medication errors in a hospital setting. Further, problem formulation in such cases requires a quantification of the latent factors influencing the medication error system.

7. Limitations

A broader perspective is required to study the medication error from the SCM perspective. To implement such processes, a considerable amount of time and effort must be invested in health systems (Teo et al., 2023). The Indian context of the medication error is way more complex than its Western counterparts (Singh et al., 2025). The public-private hospital setting of the

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Indian hospital needs an understanding from the communication perspective of the health setting (Bhowmick et al., 2020). With the requirement of an adequate amount of time, these studies also help in understanding the vision and mission of the organisation. The SCM method can help only in analyzing situations from the mental models, but it cannot give tangible or working solutions, such as a user interface or a product designed to avoid medication errors. The SCM method to study medication errors is insufficient to capture the factors such as noise, workload, environmental conditions, equipment, and related protocols on occurrences of medication errors (Carayon, 2012). Some elements and factors, such as data reliability and quantifying complex behavior, are difficult to understand with the help of SCM. These factors must be taken into consideration when designing for medication errors. The medication system, when analyzed with SCM, shows several vulnerabilities that lead to harm penetrating through its layers (Banja, 2004). Each layer of SCM represents a layer of mechanism, such as organizational policies and procedures, clinical protocols and guidelines, technology safeguards and tools, supervision and oversight, and individual vigilance (Perneger, 2005). To better understand the healthcare defenses, designers should analyze the layers of SCM. Under some conditions, as discussed in the example, see Figure 2, the holes in the problem of medication errors need a clear understanding of the complexity of infrastructure, resources, and the attitude of patients. Hence, the Indian healthcare setting needs the SCM and other resources for the logistics and critical evaluation of the holes in the medication error (Singh et al., 2025). Hence, the layers are one policy, two nurse workloads, three cognitive biases, and four visual inspections. This comparison will give a comprehensive perspective on error propagation at a higher level (see Figure 1).

The layer-wise structure of SCM has many barriers, and it is difficult to predict the one-to-many causal mapping for medication errors (Wiegmann et al., 2022). A prospective study on the applicability of SCM for the prediction of medication errors and medication policy making. Even though SCM can predict medication errors, it cannot address the causal factors. These interventions help in a prospective study of reducing medication errors in domains such as medication management, medication error management, and medication safety for the nursing staff. Exploring the dynamics and interdependencies from a system perspective will help develop insightful, detailed, and comprehensive strategies for addressing the complex, multifaceted nature of medication errors.

Overall, SCM suggests a layered approach to address the complex issue of medication errors, comprising look-alike and sound-alike medicine labeling and naming (Crane and Crane, 2006).

These approaches help practitioners add government agencies to address the incidence of medication errors (Bogner, 1994).

8. Outcomes

In this overview, we have discussed and defined the perspective of the application of the Swiss cheese model for the comprehensive understanding of medication errors and the preventive targeted interventions. SCM comprises various layers; within these layers, the holes represent the errors. The propagation of the errors in the layers represents the errors that can cause harm to the patient (see Figure 2). The checks on the system-level error propagation. These factors are communication skills, communication effectiveness, and error reduction. The SCM helps explain the organizational factors that influence medication errors. Poor supervision of the behavior of the household and primary caregivers is a hidden factor for the medication errors. The holes in the layers of the SCM are human errors, equipment malfunctions, or environmental hazards that result in the accident and have the potential to damage the system.

Hence, while designing a new system for the medication application, it is important to consider the SCM recommendations on medication errors. The Swiss cheese model can be applied in error-monitoring techniques to improve the quality of existing healthcare systems (Barker, 1995). SCM came up as a model for system safety, where a single layer penetrates the end of the medication system. This model reveals the complexities in a health system. It also illuminates vulnerabilities like gaps between system layers, which could aid in building error-related solutions. The ambiguity and lack of understanding of the medical labels represent the potential holes in the first layer of defence. The holes are caused by a variety of factors, including communication effectiveness and error reduction. SCM is a snapshot of the proactive (possible) errors that can happen. SCM offers a layered perspective on how the failures interact and evolve. In conclusion, it can be stated that SCM helps in the identification, layering, and mapping of medication errors in the Indian context.

Such outcomes related to the medication error system help deliver the right amount of information on the labeling. System dynamics certainly helps product managers in understanding the underlying causes and patterns of medicine-related errors. This results in enhancing the medication naming and labeling quality. The model shall help in predicting meaningful steps to understand better and curb medication errors.

9. Conclusions

The present research findings underscore the significance of a hybrid approach in understanding medication error in the Indian context. This comparative study establishes the most effective theoretical framework for addressing Indian medication errors. The variables in this theoretical framework consist of factors such as organizational culture, resource availability, healthcare worker training, education, communication, and regulatory environment. SCM and its methodology help in understanding the factors in medication errors. The SCM highlights how multiple layers of defense can fail during ADE, emphasizing that errors are never caused by a single event; rather, they are caused by a chain of events. SCM establishes the correlation between various factors that cause medication errors (Cohen, 2017). It is also a well-established tool to identify medication errors, but the interrelationship and cause-and-effect relation between various factors of medication error have not been studied solely by using the SCM. The function of the medication error system is to work within the system's limitations, predict the system capacity. If the system capacity is not enhanced, then medication errors will overtake the number of right medicines given in any scenario. Medical labeling problems significantly affect the factors related to medication error. These factors link to issues of medicine disposal and administration. A systems perspective will prevent the users and patients from blaming the individual for the medication error.

System mapping starts with the cluster model, which comprises the group interactions between the elements of medication error. The cluster model in systems thinking is recommended to be considered before creating a causal loop diagram. The causal model and cluster model tell the context of the system modeling and help the system designers for future interventions.

Challenges related to error encapsulation span both system and subsystem levels. The medication error is related to the various aspects of medication skill acquisition, training, decision-making, and feedback and debriefing. The debriefing section of the medication error is necessary to highlight and emphasize the importance of strategies such as education, debriefing, constructive feedback, peer support, and mentorship in the process of learning from medication errors.

Understanding the interdependence of SCM contributing to medication errors can help improve patients' adherence to medical information. One of the primary challenges in addressing the medication errors lies in the complex interconnected elements of the healthcare system (Lauffenburger and Choudhry, 2018). Therefore, the designers should take into consideration SCM factors to understand the medication errors holistically (Anderson and Webster, 2001).

The medication system is already under huge pressure to prevent medication errors (Crane and Crane, 2006). Adopting a systems thinking approach is necessary to address the complex challenges of medication errors. Medication errors are not avoidable, but can be forecasted and avoided by proper system redesign (Crane and Crane, 2006). The SCM helps reduce error rates and the cost of medical care (Bogner, 1994).

Reducing medication errors using factors of SCM will benefit the whole Indian healthcare system. Medication errors need a systems-thinking approach to comprehend SD factors instead of blaming human errors.

Integration of such complementary methodologies helps in comprehensively understanding the design interventions and policies to reduce medication errors (Da Silva and Krishnamurthy, 2016).

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