Journal of Infrastructure, Policy and Development 2024, 8(12), 8611.
https://doi.org/10.24294/jipd.v8i12.8611

Article

Mitigating anticipated medicine shortages through inter-facility medicine sharing

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CITATION

Tippong D, Jomthanachai S, Dankittikul T. (2024). Mitigating anticipated medicine shortages through inter-facility medicine sharing. Journal of Infrastructure, Policy and Development. 8(12): 8611.
https://doi.org/10.24294/jipd.v8i12.8611

ARTICLE INFO

Received: 15 August 2024
Accepted: 23 September 2024
Available online: 4 November 2024

Abstract: This study develops an optimisation model to facilitate inter-facility medicine sharing in response to anticipated medicine shortages. These facilities include hospitals and medical representatives. We adopt the concept of collective response proposed in our study literature. The optimisation model is developed according to the real-world practices of inter-facility medicine sharing. We utilise case studies of particular healthcare networks to demonstrate the efficacy of the developed model. The efficacy encompasses the model's application to real-world case studies, as well as its validity and reliability within a specific system. The results show that the developed model is able to determine which facilities should share the requested amount of medicines; and to reduce total lead times by at least one day compared to the ones obtained in the current practice. The model can be used as a decision-support tool for healthcare practitioners when responding to shortages. The study presents the managerial implications of medicine sharing at the network level and supports the development of collaboration amongst facilities in response to medicine shortages.

Keywords: medicine sharing; medicine shortage; network; collaboration; lead time

1. Introduction

One of the challenges in promoting care services in hospitals is to ensure a sufficient inventory of medicines for treatments. Shortages of active pharmaceutical ingredients, manufacturing problems, ineffective management of supplier contracts, financial restrictions, and volatile demands are leading causes of medicine shortages (Miljković et al., 2020; Modisakeng et al., 2020). The shortages are a complex problem that has been reported by practitioners in hospitals around the world (Abu Zwaida et al., 2022; Heiskanen et al., 2015; Tan et al., 2016; Zovi et al., 2021;) and could impact patient care, safety, and recovery experiences (Orlovich et al., 2020; Saedi et al., 2016; Said et al., 2018).

Implementing medicine sharing among hospitals can mitigate the effects of medicine shortages and enhance service levels within healthcare networks (Bozkir et al., 2021). Medicine sharing employs the strategy of matching capacity to volatile demands to minimise the impact of insufficient medicine. The demand for a particular medicine might be higher in some hospitals than in others, thereby leaving some hospitals with a shortage of that medicine, and others with an excess. Hospitals with shortages could thus receive aid from those with a surplus (Tippong et al., 2022), a strategy known as collective response. The practices of medicine sharing can be found in both disaster and non-disaster events. During the COVID-19 pandemic, when medicines at the Wuhan Red Cross were in shortage, Red Cross in other cities in China shared with them some medicine to reduce the spread of COVID-19 in China

(CNN.com, 2020). Hospitals in Italy and the United States shared their medicines in response to a surge of infected patients and to relieve negative health outcomes such as the number of casualties (Carenzo et al., 2020). During the pandemic flu, the United States developed regional aid through the sharing of antiviral drugs (Arora et al., 2010). They employed a strategy of matching capacity to fluctuating demands in order to minimise the number of infections and deaths. A proportion of antiviral drugs was initially allocated to each region for the treatment of the expected infected population. Regions experiencing a higher impact from the pandemic might face shortages, while others had surpluses, facilitating mutual aid. For non-disaster events, hospitals in the healthcare network have employed a medicine-sharing approach in the form of lending (Omer et al., 2021). According to the observations we conducted in healthcare facilities, hospitals anticipating medicine shortages often request medicine from nearby healthcare facilities that are capable of sharing. These facilities include hospitals and medical representatives.

This study develops an optimisation model to facilitate medicine sharing among facilities in response to anticipated medicine shortages. For our study, we adopt the concept of collective response proposed in the literature. The optimisation model incorporates the practices of inter-facility medicine sharing, as well as the availability of medicines at each facility. The model utilises data on the medicines that are going to be in short supply and the projected surplus of the medicines. This surplus represents the quantity of medicines that facilities can share without affecting their healthcare service quality. The study aims to reduce the total lead times for medicine acquisition compared to the total lead times obtained in current practices. Total lead times are duration between placing medicine requests and receiving the requested medicines from all facilities.

The contributions of our study are as follows: The model can be used as a decision-support tool when responding to shortages. The application of Excel Solver allows operational practitioners in hospitals to make decisions at a relatively low cost because Excel Solver is a tool available for Windows-based software and Apple's macOS. Consequently, the proposed model will assist practitioners in acquiring medicines expected to be in short supply through a medicine-sharing approach. Furthermore, this study will present the managerial implications of medicine sharing at the network level and support the development of collaboration amongst facilities in response to medicine shortages.

The paper is divided into 7 sections. Section 2 reviews the literature proposing approaches to mitigate medicine shortages. Section 3 describes the methodology, practices of medicine sharing, and the development of the optimisation model. Section 4 presents case studies used to demonstrate the efficacy of the proposed model for medicine sharing. Section 5 illustrates the model results and discusses the findings. Section 6 discusses managerial implications and impacts on policies. Finally, Section 7 concludes the study and suggests future research work.

2. Literature review

Several approaches have been proposed to address the problem of medicine shortages. For example, Kifle et al. (2021) and Keene et al. (2022) investigated the use of substitute and alternative medicines with opinions from health professionals in response to medicine shortages. However, this strategy is not commonly used due to low treatment response rates. Treatment response demonstrates a sufficient symptom reduction to a particular treatment. Some patients may have positive response to a specific medicine, but not to substitutes or alternatives.

Some studies addressed the problem of medicine shortages from a supply chain perspective. Jia and Zhao (2017), Traoré et al. (2023) conducted scenario analysis based on industry data to identify solutions to medicine shortages. Their models incorporated the interests of relevant parties, including medicine manufacturers, distributors, governments, and healthcare providers. They highlighted that procurement officers should properly manage medicine purchase contracts to avoid procurement issues and medicine shortages in the long term. Abu Zwaida et al. (2021) developed a dynamic optimisation model for medicine refilling decisions. The focus was on the prevention of medicine shortages, rather than responding to the shortages. The objective of their study was to maximise hospital profits while considering refilling costs, medicine costs, storage costs, and penalty costs for shortages and overstock problems. Recently, Liu et al. (2022) proposed a centralised medicine procurement system in which a central warehouse was responsible for purchasing and replenishing medicines for hospitals. The study employed a simulation approach to evaluate the effectiveness of medicine acquisition under the centralised procurement system. However, the application of centralised procurement involved long lead times and could not provide immediate replenishment of medicines for hospitals in the event of a sudden increase in demand, as the safety stock was unable to recover. The centralised procurement system may not be viable if delivery scheduling becomes time-consuming. Therefore, the primary disadvantage of the system is that urgent requests are delayed due to the increased number of actors involved in a centralised model, necessitating the detailed protocols regarding timing and responsibilities within the procurement process (Skipworth et al., 2020).

In addition, a forecasting approach, along with some techniques/algorithms, has been used to prevent medicine shortages as well as reduce inventory forecast errors. For instance, Hussein et al. (2015) employed data mining techniques to implement medicine inventory forecasting for medicine consumption in upcoming periods in a drug store. Kanyakam et al. (2018) presented an inventory management model with the aim of improving medicine inventory control while enhancing patient satisfaction in hospitals. They implemented ABC-VED matrix analysis to define vital and expensive items and used an exponential smoothing technique to predict future demands for such items. Similarly, Jorge et al. (2022) and Kalaya et al. (2023) investigated forecasting techniques, namely the Croston method, a combination of exponential and Poisson distribution, and compared their performances. Their goal was to propose appropriate techniques and medicine inventory control policies in hospitals. To effectively manage medicine inventory through the application of a predictive strategy, expertise in forecasting and inventory management is essential. The inventory level for upcoming periods is determined by the forecast error obtained using these forecasting techniques. Decisions on inventory levels are typically made using the technique with the lowest forecast error. This implies that the actual demand may be lower or higher than the forecasted level. This may challenge hospitals in applying a forecasting approach to prevent medicine shortages, especially when demand patterns are irregular or highly fluctuating. To address the challenges posed by unexpected or unanticipated demand, practitioners may utilise advanced solutions given by machine learning. The cost of introducing predictive approaches for medicine inventory management often includes an investment in technology, ongoing system maintenance, and specialised training for existing staff. This implementation strategy may face limitations in developing nations (Kihara and Ngugi, 2021).

A study by AlAzmi and AlRashidi (2019) demonstrated success in managing shortages by facilitating medicine sharing between hospitals at the network level. The objective was to reduce overstocked medicines and mitigate medicine shortages. They employed a process map to review potential causes for medicine shortages and strategies for facilitating medicine sharing in the Kingdom of Saudi Arabia. They found that practitioners need simple applications, such as Telegram, for connecting with other hospitals when handling medicine sharing. More than 90% of overstocked medicines were redistributed to hospitals experiencing shortages, covering two-thirds of medicine shortage requests.

Our study develops an optimisation model to facilitate inter-facility medicine sharing in response to anticipated medicine shortages. The shortages can be caused by manufacturing problems, ineffective supply chain management, financial restrictions, physician prescribing behaviour, volatile demands, and forecast errors. We adopt the collective response proposed by AlAzmi and AlRashidi (2019), Bozkir et al. (2021) and Tippong et al. (2022) in our study. The collective response allows for the pooling of overstocked medicines to ensure the continued provision of medical services within the network. Hospitals with shortages could receive mutual aid from facilities with surpluses. In addition, based on our observations in Thailand, hospitals anticipating medicine shortages typically request medicines from nearby facilities that are capable of sharing. These facilities include hospitals and medical representatives. Nevertheless, the selection of facilities is often based on personal experiences and contact. This sometimes results in long lead times for medicine acquisition. Thus, the study aims to reduce the total lead times compared to the current practices.

The contributions of our study are as follows: We develop an optimisation-based medicine sharing approach primarily to mitigate anticipated medicine shortages. The optimisation model, incorporating the practices of inter-facility medicine sharing as well as the projected availability of medicines at each facility, is implemented using Excel Solver, available on Windows-based software and Apple’s macOS. Thus, the model can serve as a low-cost decision support tool. Ultimately, this can help inventory planners develop a more effective collective strategy for managing medicines while maintaining healthcare services.

3. Methodology

3.1. Data collection

We used observations to collect the data on the practices of inter-facility medicine sharing when responding to anticipated shortages. The observations were conducted in the departments of inventory control in hospitals, and medical representatives in Thailand. Furthermore, we collected quantitative data on the list of medicines that are often in short supply, their monthly medicine consumption and inventory levels, and the lead time for medicine acquisition. Lead time is the duration between placing medicine requests and receiving the medicines from a particular facility.

3.2. Practices of inter-facility medicine sharing

The following practices of inter-facility medicine sharing are based on observations made in Thailand. The healthcare facilities involved in medicine sharing when managing anticipated shortages include secondary and tertiary hospitals in the same healthcare service area, nearby hospitals outside the area, and medical representatives. It should be noted that secondary hospitals provide medical services for specific systems of the body and non-severe health conditions, while tertiary hospitals offer advanced medical investigations and specialised care for severe health conditions. The practices of inter-facility medicine sharing are contingent upon the size of the hospitals anticipating medicine shortages. Specifically, secondary hospitals tend to request medicines from other secondary or tertiary hospitals, whether inside or outside their service area. They rarely request medicines from medical representatives. On the other hand, tertiary hospitals typically request medicines from other tertiary hospitals or medical representatives. **Figure 1** illustrates the practices of inter-facility medicine sharing when managing anticipated shortages. The arrows indicate the flow of requests for medicine acquisition.

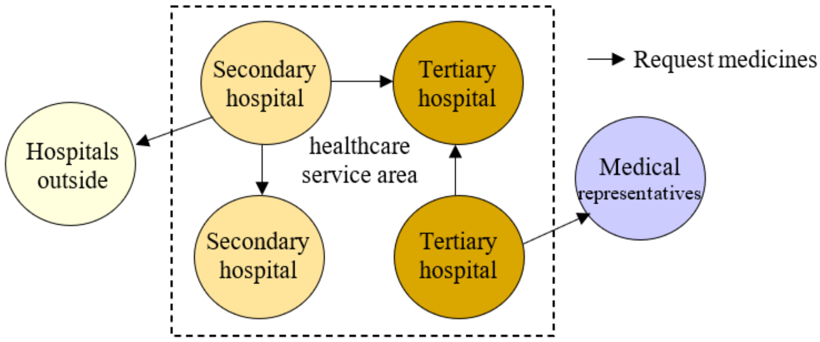

Figure 1. Practices of inter-facility medicine sharing in response to anticipated shortages.

It should be noted that the hospitals acquiring the shared medicines must either 'return the same amount when they are available' or 'make payment via credit' to the facilities providing the medicines. However, these matters are outside the scope of the model, as the study focuses on sharing medicines among facilities to mitigate medicine shortages while achieving low total lead times.

3.3. Development of optimisation model

The optimisation model is developed according to the practices of medicine sharing obtained from observations. The study aims to reduce the total lead times for medicine acquisition compared to the total lead times obtained in current practices. Total lead times refer to the duration between placing medicine requests and receiving the requested medicines from all facilities. The model's indices, sets, and variables are presented in **Table 1**.

Table 1. Indices, sets, and variables with their descriptions.

Indices and variables	Descriptions
A	Set of secondary hospitals
B	Set of tertiary hospitals
C	Set of hospitals outside the healthcare service area
D	Set of medical representatives
I	Set of hospitals that request medicines; $\{A, B\} \in I$
J	Set of healthcare facilities capable of sharing medicines; $\{A, B, C, D\} \in J$
i, j	Index of hospitals requesting medicines and facilities providing medicines, respectively
l_{ij}	Lead time - duration between hospital i placing medicine requests and receiving the medicines from facility j (hours)
v_i	Projected amount of medicines that hospital i will be short of (units)
u_j	Projected amount of medicines that facility j is able to share with others (units)
m_{ij}	Amount of medicines that hospital i acquires from facility j (units)
x_{ij}	Binary variables indicating hospital i acquires medicines from facility j

The decision variables are defined to determine the amount of medicines hospitals acquire from other facilities. The objective function aims to minimise the production of shared medicines and lead times, as expressed in Equation (1). The objective function incorporates the lead times spent on medicine acquisition. As a result, hospitals with shortages tend to acquire requested medicines from the facility with the surplus and the shortest lead time. We measure total lead times using Equation (2), where total lead times are evaluated based on the maximum lead time spent acquiring the requested amount of medicines from all facilities.

$$Minimise(\sum_{i=1}^{I}\sum_{j=1}^{J} m_{ij} \times l_{ij}) \quad (1)$$

$$Maximum(\, x_{ij} \times l_{ij}), where\ x_{ij} = 1\ if\ m_{ij} > 1, otherwise\ x_{ij} = 0 \quad (2)$$

Constraints:

$$\sum_{j=1}^{J} m_{ij} = v_i\ (\forall i \in I), (I \neq J) \quad (3)$$

$$\sum_{i=1}^{I} m_{ij} \leq u_j\ (j \in J), (I \neq J) \quad (4)$$

$$\sum_{j=1}^{J} m_{ij} = v_i\ (i \setminus \{B\}), (\, j \setminus \{D\}), (I \neq J) \quad (5)$$

$$\sum_{j=1}^{J} m_{ij} = v_i\ (i \setminus \{A\}), (\, j \setminus \{A, C\}), (I \neq J) \quad (6)$$

$$m_{ij} \geq 0, Integer \quad (7)$$

Constraint (3) dictates that hospitals with anticipated shortages acquire the requested amount of medicines. Constraint (4) ensures that the facilities do not allocate more than their projected surplus of medicines. Please note that practitioners typically report foreseen shortages at least 5 days in advance (Turbucz et al., 2022; Vogler and

Fischer, 2020). Constraint (5) specifies that secondary hospitals can receive medicines from any facilities except medical representatives. Constraint (6) dictates that tertiary hospitals can receive medicines from other tertiary hospitals or medical representatives. Constraint (7) imposes non-negative bounds.

4. Case studies

The study utilises data from two healthcare networks in different regions to evaluate the efficacy of the proposed optimisation model. The efficacy encompasses the model's application to real-world case studies, as well as its validity and reliability within a specific system.

The healthcare networks are in Songkhla and Phuket, Thailand, with different network sizes. The healthcare network in Songkhla consists of five facilities, including two secondary hospitals and one tertiary hospital located in Songkhla, one hospital outside Songkhla, and one medical representative. Meanwhile, the network in Phuket comprises six facilities, including three secondary hospitals and one tertiary hospital located in Phuket, one hospital outside Phuket, and one medical representative.

4.1. Healthcare network in Songkhla

The hospitals in Songkhla often experience shortages of Intravenous Immune Globulin (IVIG), Actilyse, Etomidate, and DTP non-cellular. We selected IVIG to demonstrate the efficacy of the proposed model because these hospitals frequently face shortages of the IVIG during the same period each month, from the 25th–30th. Their inventory cycle is monthly, which is a common practice (San-José et al., 2019). As such, they do not purchase medicines until the first week of each month. **Table 2** presents the data on IVIG availability and demand of the healthcare network in Songkhla.

Table 2. Data on IVIG availability and demand of the healthcare network in Songkhla (units).

Date	Secondary hospital 1		Secondary hospital 2		Tertiary hospital	
	Availability	Demand	Availability	Demand	Availability	Demand
25	0	5	3	1	45	10
26	0	6	0	3	29	12
27	0	4	0	2	20	10
28	0	9	0	3	15	9
29	0	5	0	2	0	10
30	0	3	0	1	0	11

The lead time for medicine acquisition among facilities is shown in **Table 3**, in which the dash (-) means medicine sharing between particular facilities cannot occur as mentioned in Section 3.2.

Table 3. Lead times for medicine acquisition among facilities in Songkhla (hours).

Medicine requests are made from	Medicine requests are sent to				
	Secondary hospital 1	Secondary hospital 2	Tertiary hospital	Hospital outside	Medical representative
Secondary hospital 1	-	24	24	48	-
Secondary hospital 2	24	-	24	48	-
Tertiary hospital	-	-	-	-	72

4.2. Healthcare network in Phuket

Medicine shortages are also found in Phuket. However, the hospitals in Phuket often experience shortages of Actilyse during the 25th–30th of each month. Their inventory cycle is also monthly. **Table 4** presents data on Actilyse availability and demand in the healthcare network, while **Table 5** shows the lead time for medicine acquisition among facilities in Phuket.

Table 4. Data on Actilyse availability and demand of the healthcare network in Phuket (units).

Date	Secondary hospital 1		Secondary hospital 2		Secondary hospital 3		Tertiary hospital	
	Availability	Demand	Availability	Demand	Availability	Demand	Availability	Demand
25	0	10	5	3	3	2	52	17
26	0	12	4	1	0	1	29	15
27	0	8	0	2	0	3	20	10
28	0	9	0	4	0	4	15	12
29	0	10	0	2	0	3	0	15
30	0	9	0	1	0	2	0	12

Table 5. Lead times for medicine acquisition among facilities in Phuket (hours).

Medicine requests are made from	Medicine requests are sent to					
	Secondary hospital 1	Secondary hospital 2	Secondary hospital 3	Tertiary hospital	Hospital outside	Medical representative
Secondary hospital 1	-	24	36	24	48	-
Secondary hospital 2	24	-	36	24	48	-
Secondary hospital 3	36	36	-	36	48	
Tertiary hospital	-	-	-	-	-	72

Notably, the total lead times in current practices take approximately 3 days or 72 hours. The hospitals in Songkhla and Phuket with anticipated shortages of IVIG and Actilyse mostly request the medicines from medical representatives. They state that they select medical representatives because the representatives are certain to provide the requested amount of IVIG and Actilyse.

5. Results and discussions

The Excel Solver tool is used to assess the amount of medicines shared among facilities and to reduce the total lead times. **Figures 2** and **3** illustrate the model results representing the sharing of IVIG in Songkhla and the sharing of Actilyse in Phuket, respectively, during the 25th–30th. The arrows indicate the flows of the medicine requests. For example, in **Figure 2**, Secondary hospital 1 requests IVIG from Secondary hospital 2 and the tertiary hospital on the 25th. Both Secondary hospital 1 and Secondary hospital 2 request IVIG from the tertiary hospital on the 26th. The model results correspond with the practices of medicine sharing described in Section 3.2.

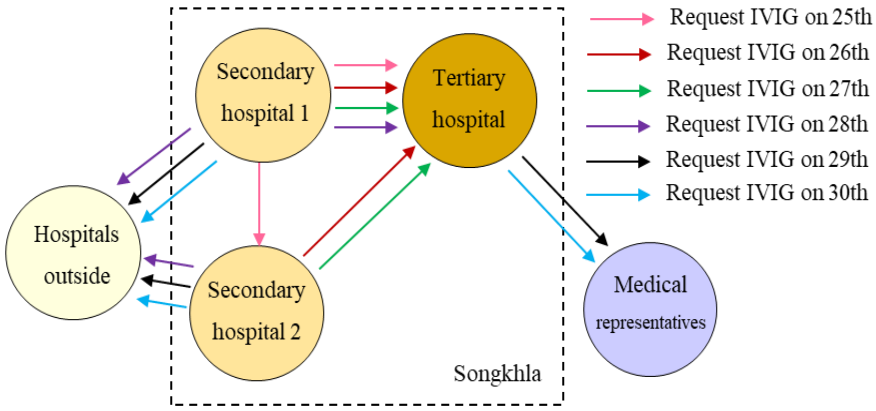

Figure 2. Medicine sharing among facilities in Songkhla on selected days.

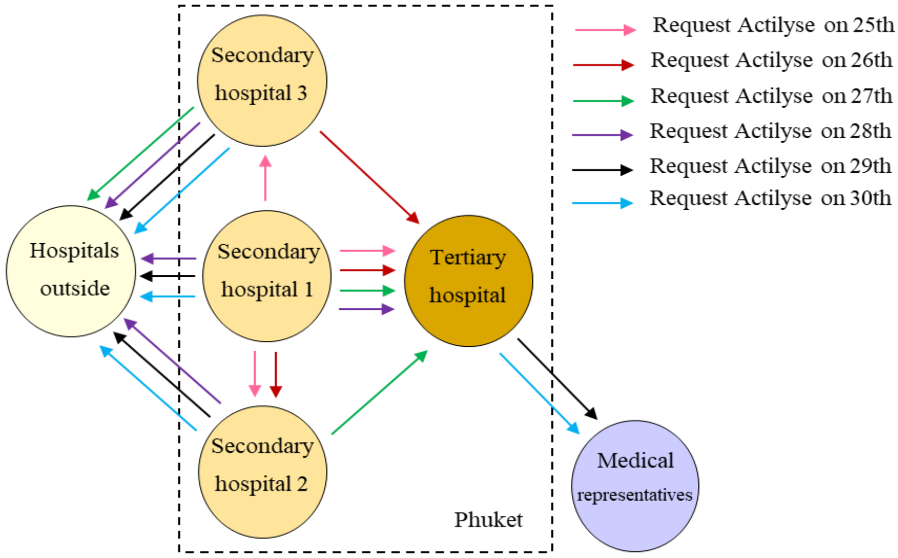

Figure 3. Medicine sharing among facilities in Phuket on selected days.

Furthermore, in both Songkhla and Phuket, the total lead times of secondary hospitals decrease to at most 2 days on the selected days. Similar decreases can be found in the tertiary hospital, except on the 29th and 30th, because the tertiary hospital can only obtain IVIG and Actilyse from the medical representative, which takes 3 days for medicine acquisition. Compared to the current total lead times of approximately 3 days, the proposed model can reduce the total lead times by at least 1 day. **Figures 4** and **5** present the total lead times of all hospitals in Songkhla and Phuket, respectively.

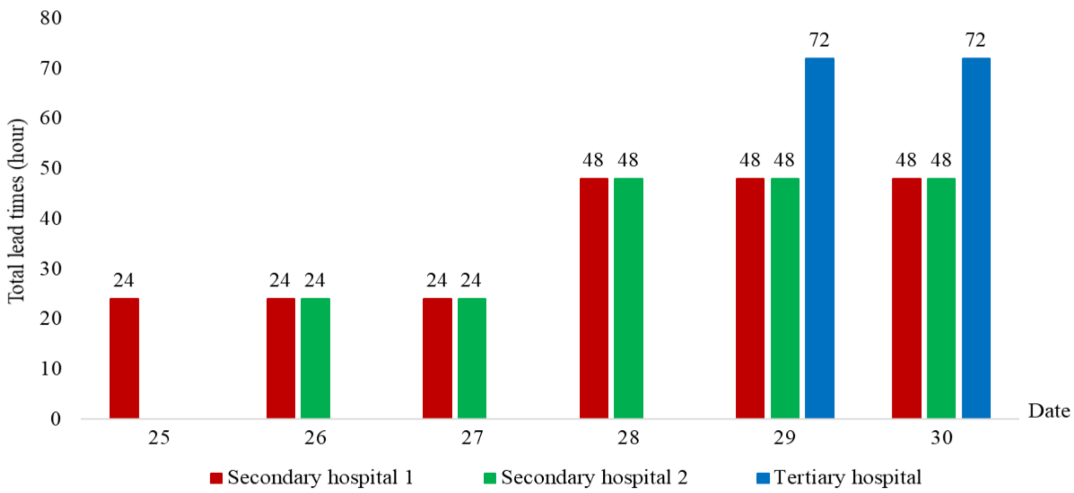

Figure 4. Total lead times of all hospitals in Songkhla obtained by the proposed model.

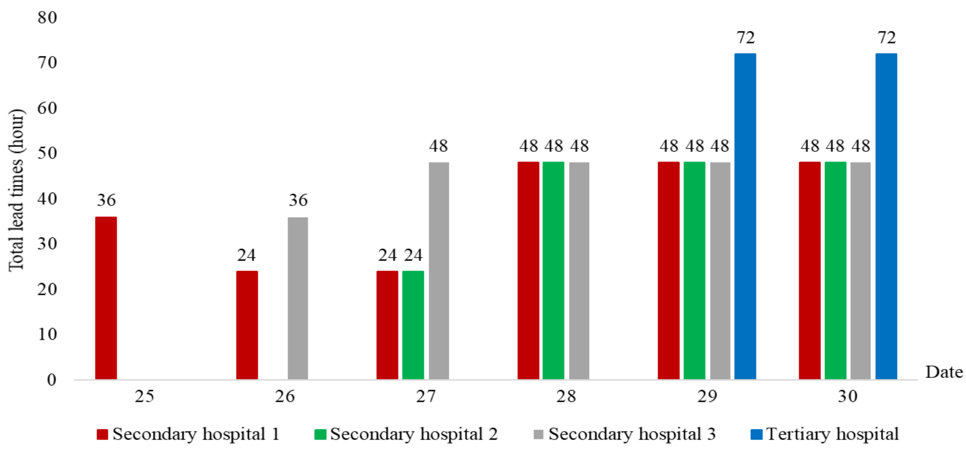

Figure 5. Total lead times of all hospitals in Phuket obtained by the proposed model.

The proposed model is capable of determining which facilities should share the requested medicines together with the amounts of medicines that should be shared with others. The model's decisions are made based on the lead time among facilities and the number of projected surpluses in all facilities. As a result, the model can yield lower total lead times.

The proposed model can be used to address the shortages of different medicines occurring in different healthcare networks of varying size and location. In simpler terms, one network, consisting of five facilities in Songkhla, experiences shortages of IVIG, while the other, consisting of six facilities in Phuket, faces shortages of Actilyse. The model results prove the efficacy of the model's application to real-world case studies in Thailand, and also demonstrate the validity and reliability of the model in this particular system.

The model has been validated by practitioners from 3 hospitals in Songkhla and 4 hospitals in Phuket. The validation includes assessing the accuracy of the solutions given by the model and evaluating the feasibility of adopting the model for their medicine-sharing planning. They state that hospitals can utilise the proposed model to address the anticipated shortages due to the availability of software for solving the model. The Excel Solver tool, which is used to solve the model, is a basic professional tool already available on most computers (Bermúdez et al., 2019). They, furthermore, state that the model offers a decrease in total lead times, which is beneficial for responding to anticipated shortages. The lead times offered by the model are also shorter than the reorder time. Consequently, hospitals with anticipated shortages can receive mutual aids from others and maintain the continuity in patient care.

6. Managerial implications and impacts on policies

The model results show that the proposed inter-facility medicine sharing model can be used to manage medicine shortages within a shorter time. Our study corresponds with studies by AlAzmi and AlRashidi (2019), Whitfield et al. (2019), and Vann Yaroson et al. (2024), which conducted surveys and interviews on strategies for mitigating medicine shortages. They reported that their participants, who are healthcare practitioners, have employed a collaborative strategy when responding to shortages. More than half of their samples typically borrow medicines from facilities with a surplus to alleviate the impact of medicine shortages on patient care. In our survey, all healthcare practitioners expressed readiness to employ the computer-based medicine sharing model to overcome the challenges of manual data exchange when sharing medicine. Alshibli et al. (2024) further note that approximately 40% of healthcare practitioners who have encountered medicine shortages in recent years expressed agreement on implementing information and communication technologies to mitigate this issue. This percentage is expected to rise as both the frequency and complexity of medicine shortages continue to increase.

This study facilitates the establishment of a medicine-sharing network, which is one form of a collaborative strategy (Tippong et al., 2022). The sharing of medicines is based on data provided by the facilities. The data includes the projected number of shortages and surpluses. A centralised database should be developed to gather the shared data, allowing the retrieval of vital information accessible to all facilities in the network (Ali et al., 2020). The database, in the form of an information technology platform supporting medicine sharing, will enhance management efficiency and foster collaboration (Adamides and Karacapilidis, 2020; Ajagbe et al., 2022). This will lead to more effective sharing of information and medicines. From a supply chain perspective, the medicine-sharing platform showing medicine availability across all hospitals in the network may support the integration of a supply chain information system, playing a vital role in managing medicine inventory in the network (Moosivand et al., 2021; Vann Yaroson et al., 2024).

To strengthen collaboration in healthcare networks, the government should initially support the development of the platform and establish policies promoting and incentivising hospitals to widely adopt the platform. To put it simply, efforts should be made to expand its use to other healthcare service areas to create a comprehensive collaborative network across various regions.

Last but not least, the involvement of medical representatives is crucial for effective medicine sharing. Their role should be to act as intermediaries, connecting diverse sub-networks across regions. They can facilitate the exchange of medicines between regions, as medicine surpluses in one area may mitigate shortages in another (Salarpour and Nagurney, 2021). This strategy enhances the efficiency of the pharmaceutical supply chain, mitigates medicine shortages, reduces waste due to medicine expiration, and fosters a sustainable medicine supply system. Ultimately, it benefits patients, aligning with the Sustainable Development Goals related to good health and well-being.

7. Conclusion

This study develops an optimisation model to facilitate inter-facility medicine sharing in response to anticipated medicine shortages. The aim is to reduce total lead times for acquiring medicines. The developed model incorporates the practices of inter-facility medicine sharing within the context of Thailand. The study demonstrates the efficacy of the model through case studies of healthcare networks in Songkhla and Phuket. The results show that the total lead times for medicine acquisition decrease by at least one day.

While this study employs the practice of inter-facility medicine sharing within the context of Thailand, the principles of collective response may be transferrable to various scenarios. The optimisation model presented here depicts the collective response through medicine sharing among facilities, and encompasses the practices of requesting medicines that are represented by a set of constraints. The proposed model establishes a baseline for future studies that could incorporate relevant laws and policies of other countries into the model. For example, some countries, such as the United States, classify hospitals into four levels including primary, secondary, tertiary, and quaternary hospitals. The levels of hospital refer to the complexity of the medical services provided by hospitals. Extensions of collective response to additional hospital levels, like primary and quaternary hospitals, remain unexplored.

The study's limitations and challenges are related to the level of information technology deployment, and the incorporation of high-level technology. Future research directions may combine the proposed model with the existing hospital inventory management systems in order to increase the practical application possibilities. This would lead to streamlined workflows, reduce manual tasks, and improve overall organizational efficiency (Linh and Lu, 2021). In this situation, the data on medicine availability would be automatically integrated into our model. Furthermore, future research directions involve the development of an optimisation model by incorporating Blockchain-based Internet of Things systems. This technology enables the efficient and transparent sharing of real-time supply and demand information, such as medicine availability, in healthcare networks (Tan et al., 2024).

Improving high-level technologies with AI (artificial intelligence) and LLMs (long language models) could enhance efficiency further. The era of AI and LLMs has emerged as a trend due to their abilities to process massive volumes of data, create useful insights, and improve communication in complicated sectors, such as healthcare organizations. AI and LLMs help improve communication and collaboration by acting as intermediaries, translating, summarising, and presenting data in an understandable format for multiple parties. This can improve healthcare information system interoperability, lower data exchange barriers, and ultimately improve patient outcomes (Hagos et al., 2024).

Author contributions: Conceptualization, DT and SJ; methodology, DT and SJ; software, DT; validation, DT, SJ and TD; formal analysis, DT, SJ and TD; investigation, DT and SJ; data curation, DT; writing—original draft preparation, DT; writing—review and editing, DT, SJ and TD; visualization, DT. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: We are grateful to the healthcare practitioners in Thailand for accepting to take part in the validation of the developed optimisation model.

Data availability: The optimisation model developed in the Excel Solver tool is available upon request from the corresponding author. The model is not publicly available due to it containing information that could compromise the privacy of research participants.

Conflict of interest: The authors declare no conflict of interest.

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