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Enhancement of patient and staff experience at outpatient pharmacy via optimization of drug–shelf reallocation

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ABSTRACT

The drug–shelf allocation planning problem of an outpatient pharmacy entails assignment of drugs to shelves. It is a challenging combinatorial problem due to its underlying safety precautionary measures and operational constraints, such as that drugs of similar names should not be placed together, oral drugs should not be placed together with non-oral drugs, and mixtures must not be placed above non-mixtures. A good drug–shelf allocation plan is critical to an outpatient pharmacy due to its impact on both patients and pharmacy staff. Despite the importance of the drug–shelf allocation planning problem, it has received limited attention in the literature. This paper aims to fill this research gap by introducing a new three-stage solution framework to solve the drug–shelf allocation planning problem where the latter is decomposed into three sub-problems. Respectively, they aim to determine (1) the drug–shelf allocation plan of selected drugs which requires the minimal number of shelves, (2) the drug–shelf allocation plan of the remaining drugs which maximizes the number of prescriptions which can be filled from one shelf, and (3) the drug storage plan of each shelf which minimizes the distance travelled by its packer. In our solution framework, the first sub-problem is solved manually while the other two sub-problems are addressed by solving two integer linear programming models. To illustrate its practical relevance and effectiveness, this paper also shares the computational experience of the new solution framework on a drug–shelf allocation planning problem of a new outpatient pharmacy at a Singapore tertiary hospital.

1. Introduction

According to the National Coordinating Council for Medication Error Reporting and Prevention (NCC MERP) in the United States, a medication error is any preventable event that may cause or lead to inappropriate medication use or patient harm. In 2006, the Institute of Medicine (IOM) estimated that 51.5 million errors occurred per 3 billion prescriptions per year based on studies and referenced research. The consequences of medication errors are dependent on type of medication error, the health status of the patient, pharmacologic classification of the drug involved, route of drug administration, and timing of drug administration. They range from minor discomfort to devastating long term disability or death. Due to uncertainty over the impact of any medication error, its prevention is paramount to patient safety.

Medication errors can be attributed to many factors [1–3] which include calculation errors, careless use of zeros and decimal points, illegible handwriting, missing information, inadequate understanding of drug product characteristics, compounding/drug preparation errors, and non-conducive work environment or staffing issues. At the organizational level, it is critical that every health care provider has a system in place that strives to minimize the occurrence of medication errors. Pharmacy staff must be comprehensively trained so that they are technically competent to manage all drugs in the pharmacy. In addition, precautionary measures must also be put in place to minimize the risk of medication errors. For example, the allocation of drugs to storage shelves in a pharmacy affects medication safety in two major ways. If the pharmacy is organized in such a way that different shelves are managed by different drug picking staff or packers, the drug–shelf allocation plan affects the workload distribution among staff involved. Uneven workload distribution is undesirable as an overworked staff is prone to medication error [4]. Moreover, it is also important that drugs with similar names are not stored in the vicinity of one another to prevent pharmacy staff from picking the wrong drugs by mistake. In fact, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) and Institute for Safe Medication

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Practices [5,6] have recommended that drugs with similar names be separated in all storage areas.

The drug–shelf allocation problem in a hospital outpatient pharmacy is complex due to the typical need to manage a large number of drugs with multitude of packaging sizes and characteristics (oral, non-oral, tablet, mixture, syrup, cream, etc.). A good drug allocation plan that minimizes medical errors and equalizes workload distribution among pharmacy staff is not obvious, especially when the demand trends of all drugs involved need to be accounted for. Despite the prevalence and complexity of drug–shelf allocation problems in hospital outpatient pharmacies, there is a paucity of research addressing these problems. To the best of the authors' knowledge, there has been little or no study on this subject. In contrast, shelf-space allocation problems in the retail industry have received more attention by the research community. To date, several models and algorithms [7–14] have been developed to support retailers in making shelf-space allocation decisions. These models were developed with account of retail spatial effect on sales and their solutions could potentially improve inventory return investment as well as consumer satisfaction by reducing the likelihood of products being out of stock. However, their application potential in addressing the drug–shelf allocation problem of hospital pharmacies is limited due to the underlying differences in operating objectives and the constraints of hospital pharmacies and commercial retailers. In this paper, we aim to fill the research gap in the domain of drug–shelf allocation in hospital outpatient pharmacies by introducing a novel three-stage solution framework approach. The latter accounts for the key relevant operational and safety constraints that pharmacy operators have to contend with. To illustrate its practical relevance and effectiveness, this paper also shares the computational experience of the new solution framework on a drug–shelf allocation planning problem of a new outpatient pharmacy at a Singapore tertiary hospital.

2. Problem description

Singapore General Hospital (SGH) Outpatient Pharmacy was merging two existing facilities to form a new entity which was to be ready in 2012. The new pharmacy incorporates new infrastructures like pre-packing machines and a conveyor belt system as well as a new work flow process. All drugs ($i = 1, \dots, N$) in the new facility are to be stored in gondolas ($g = 1, \dots, G$) where N and G denote the total number of available drugs and gondolas in the outpatient pharmacy respectively. Every gondola (see Fig. 1) consists of shelves ($s = 1, \dots, S$), each of which consists of rows that are designed to hold drugs in one of the storage modes ($t = 1, \dots, T$). Note that S refers to the total number of shelves in a gondola while T is the total number of storage modes in the outpatient pharmacy. In our study, there are only two storage modes to consider, namely bins and boxes. Sets of drugs that are to be stored in bins and boxes are denoted by **BIN** and **BOX** respectively. The bins that hold drugs come in two sizes (i.e. big and small). A row that is assigned to hold bin drugs is to contain either four big bins or six small bins with no mixture of both bin types. In addition, each gondola is manned by a packer who is responsible for picking drugs from this gondola to fill any incoming prescription orders ($p = 1, \dots, P$) that require drugs from the aforementioned gondola where P is the total number of prescription orders received. All drugs of a prescription order that originate from a gondola are to be packed into one or more baskets before the latter are placed in a conveyor belt system and subsequently consolidated with other baskets which correspond to the same prescription order. Once all the baskets of drugs that correspond to a prescription order are ready, they are placed together in a queue for dispensing to the patient concerned at the dispensing counter.

Fig. 1. A gondola at the new outpatient pharmacy.

SGH Outpatient Pharmacy has to manage more than a thousand different drugs and a work load of more than one thousand prescription orders on a daily weekday basis. Due to medication safety reason, it is crucial to equalize the workload distribution among the packers so that none of them is overworked. Moreover, it is also important to ensure all drugs are assigned to the gondolas with the following constraints for every gondola.

(a) Oral drugs should not be on the same row as non-oral drugs.
(b) Non-oral drugs should not be stored above oral drugs.
(c) Mixtures should not above oral drugs in a gondola.
(d) Drugs with similar spellings should not be on the same shelf in a gondola.
(e) Each shelf should hold either big or small bins.
(f) Unless separated by a concrete pillar, the entire shelf that spans across the width of a gondola should hold either oral or non-oral drugs.

In this study, seven gondolas were considered for storage of drugs at the new outpatient pharmacy and their respective available spaces are illustrated in Fig. 2. It is important to note that conveyor belt system of the new pharmacy has a capacity limit on the number of baskets it can handle at one time. Thus, the assignment of drugs to gondolas should be done with the goal of maximizing the number of prescription orders that require drugs originated from only one gondola. This will not only minimize the number of baskets placed in the conveyor belt system. Potentially, it can also cut down the waiting time of patients since it eliminates the need to wait for baskets of drugs from multiple gondolas to be ready for dispensing.

On the whole, the drug storage planning problem aims to determine the drug–shelf allocation plan that satisfies the above-mentioned storage constraints. In addition, the problem has the multiple objectives of equalizing workload distribution among the packers, maximizing the number of prescription orders that requires drugs to be picked from single gondolas, and minimizing the total walking distances of packers over a period of interest.

3. Problem formulation

Due to the inherent complexity of storage constraints (a)–(c) and the need to keep the formulated problem tractable, the above drug storage planning problem was not addressed as a standalone optimization model. It is interesting to note that once mixtures and