DESIGN OF A USER DRIVEN REAL TIME ASSET TRACKING SYSTEM USING RFID IN A HEALTHCARE ENVIRONMENT

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CHAPTER I

INTRODUCTION

Improper resource allocation is one of the perennial problems in healthcare systems. Providing the right resources at the right time in the right quantity is important, as failure to comply may result in patient death, reduced customer value or lost revenue [1, 2]. Healthcare system needs a strong information system to address the effective resource tracking system. The shift from “non-profit” to “for-profit” healthcare organizations has caused healthcare to focus on the robustness of their information systems [2, 3]. Healthcare resource management can be regarded as a separate area of research as it involves a measure of uncertainty which is different from any other service industry due to the unpredictable patient mix [4, 5].

Researchers have focused on the design of information systems in healthcare and the use of RFID technology can be considered an important aspect in such designs [6, 7]. RFID technology uses wireless identification techniques and can help to effectively track resources and improve the visibility of the resource management system overall. As RFID readers are costly, the economic constraints do not allow having as many readers as needed for full coverage of a floor plan in a healthcare system. Therefore, the number of readers is often less than needed, and the system must be designed considering the economic constraint. It becomes important to find the best location of readers for maximum coverage of the system. This research is aimed at design of an RFID network in the healthcare service sector for tracking medical assets. The following chapters discuss the use of a maximal covering approach which is a convenient tool for this specific problem. This research is focused on positioning the RFID reader to track critical assets using a maximal covering model. Critical assets are items which are limited in quantity, costly, and critical in case of emergency; it is vital for healthcare staff to find them quickly and easily. The sensor system to be built should be flexible and users should be able to change the parameters according to their needs or the assets to be tracked. This research proposes a system which is user driven and flexible.

The proposed method consists of the following steps: a) analyzing criticality of each asset in use, b) dividing hospital floor plan into square grid where each square is weighted by frequency and dwelling time of each asset type in the area, and c) creating an optimization model to evaluate the best possible reader positions.

Discrete cosine transform (DCT) is widely used in image signal processing where the image needs to be stored with minimum memory or information associated with the image [8-10]. Various properties of DCT such as De-correlation, Separability and Energy Compaction can be effectively applied in the design of a sensor system for fast calculation of the criticality index which is the main parameter in the sensor field design under consideration [8-11]. Use of DCT can significantly reduce the computations which are involved in the criticality index calculation for each square. Use of DCT properties is proposed to design the sensor field. The use of DCT properties gives fast results and can be applied to large sized grids as well as complex asset movements. A case study is proposed to depict the application, analyze the application, and demonstrate the benefits of DCT in optimizing the large sized and complex grids.

The proposed research methodology is validated with a case study implemented at Stillwater Medical Center. A comparison of the reader coverage provided by the current system versus the reader coverage using the proposed methodology is also discussed.

CHAPTER II

REVIEW OF LITERATURE

This chapter reviews healthcare system design and the aspects related to resource allocation and management. It focuses on the importance of resource tracking with the primary focus on the use of RFID technology for tracking the resources in healthcare systems.

2.1 Topology of healthcare system

A healthcare system can be viewed as a set of different entities within a centralized system. Here the entities are service providers to the centralized system. These entities work to maximize the service level of the entire healthcare system as well as their own service level. A healthcare system can be considered a serial configuration with entities in series, and dependent on other entities for the overall service level of the centralized system. The entities, though not connected to each other, work for only one goal to provide the services required by the centralized healthcare system for the care of patients [1].

The major difference between the conventional supply chain and healthcare supply chain is that the activities carried out by various entities in the healthcare supply chain do not directly affect the efficiency of the other entities. Entities/service providers are affected indirectly because variation in service level at one entity results in variation at the centralized system and eventually the centralized system reacts according to the current need. Thus, we can say that the various service providers can perform well only if others perform well.

The healthcare system can be viewed as a system where there is one centralized system asking for services. The service providers can be of two types: external service providers and internal service providers.

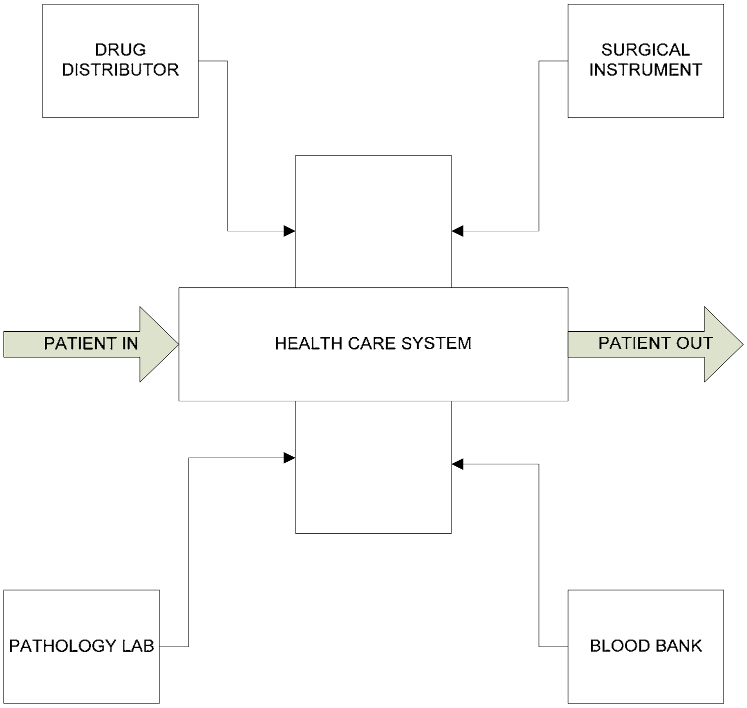


Fig. 2.1
Topology of healthcare system

External service providers: Drug distributors, surgical instrument providers, Blood bank, Pathology laboratory etc. which work for the centralized system.

Internal service providers: Doctors, Nurses, Staff associated with the hospital, other facilities.

The customers (patients) enter into the centralized system asking for services which are provided with the help of these service providers.

2.2 Tackling emergency situation from resource perspective

Increasing healthcare costs for the last three decades have led authors to have a strong assumption that, historically, healthcare systems have operated inefficiently [4]. Healthcare is governed by large number of independent sub-processes, and it is not feasible to share a common data base among them [12]. Regulations and policies have prevented developments such as Just-in-Time (JIT) concepts which can be implemented to achieve huge improvements in the overall healthcare system [4]. A shift from “not for profit” to “for profit” status has forced healthcare system owners to view healthcare as a market and a profit making source. Due to this, there are attempts to reduce costs involved in the system [4]. A strong and well-accepted information system can connect everyone in the system and can help to reduce administrative costs. Looking at the current scenario, less importance is given to the deployment of information systems in healthcare; this can be one of the major causes of demand variability in this “service” supply chain which results in high inventory and overhead costs [2].

This demand variability can result in following problems:

1. Underutilization of capacity
2. Variability in users of service
3. Inefficiencies at the operational level

The main impact of all these problems affects the performance of the centralized healthcare system. The remedial measures to improve upon the above problems are:

1. Building an information warehouse
2. Globalizing the system
3. Developing collaboration amongst the various entities of the systems

4. Optimizing the capacity and service of the system [1]

Optimizing the capacity and service means providing the right information and resources as and when needed at right location without delay. In an emergency situation, any delays can cause serious damage and low customer value.

2.3 Importance of resource allocation and resource visibility in healthcare

Improvement in healthcare supply systems would result in better inventory and resource management, and eventually more satisfied customers (patients) and more effective work flow for hospital employees [12]. Healthcare research is directed towards process and information systems improvements as it is viewed operationally different from other businesses [4]. Due to unpredictability of the patient mix, it is hard to predict the demand information, hence the proper allocation of resources has been important to analyze the trend of requirement of resources [4]. Logistics activities such as planning, designing, and implementing material flow in a system have been a prime focus in order to achieve maximum production and minimum operating cost [4, 12]. Healthcare systems need to manage their internal supply chain to maximize service levels by proper allocation of resources [3]. In a service industry like healthcare it is very important to provide the right resource at the right time and the right location [13].

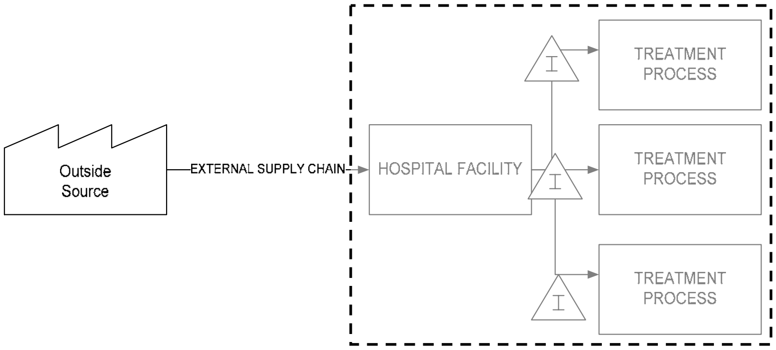


Fig 2.2
Healthcare supply chains

Effective resource management can play a vital role in improving the system. As a result, an information centre is needed which will avoid wrong/insufficient information getting shared inside the system. The healthcare industry is taking strong footsteps towards improving information systems [3]. This new strategy will help in more personalized care as information will be available when required. Robust information system will also help to keep track of the resources in the system, such as when to order and how much to order; this information can be easily shared among the stakeholders. This will help in reducing situations like wrong prescriptions, incorrect or incomplete patient information, inventory stock outs or excess inventory [3]. Characterization of healthcare systems as complex, multi-functional and information-sensitive, requires them to have a sophisticated information management system [7]. Enterprise Resource Planning (ERP) integration has become needed as competitive and public policy pressures to minimize costs are increasing [7]. ERP is a solution which binds the various departments through an integrated process operating on a common platform [5].

Resource planning is always associated with the involvement of management [7]. By adopting ERP solutions a cost reduction of around 50% can be achieved, reducing the cost invested in IT (Information Technology) budget for system integration which improves data sharing, decision making, and data integrity [7]. Still, ERP has not been able to integrate all the entities involved in the healthcare system which poses a challenging problem [7]. Improper integration and communication of processes can result in the interdependent cluster of processes operating independently which can result in incorrect process measures. Adopting ERP will help to provide more personalized care as information will be available when required.

2.4 Definition of RFID, its Benefits and limitations

This section reviews resource tracking based on a technology of radio frequency identification (RFID). IT is one of the most important resources in creating organizational value [15]. Applications of RFID are not restricted to recent years. The British Royal Air Force (RAF) used RFID-like technology in World War II to distinguish between enemy and friendly aircraft [18]. Recently, RFID has received considerable attention because of its mobility and wireless characteristics and is considered to be the next wave of the IT revolution. RFID technology has been a critical element of Auto-ID technologies recently. As inferred from its name, it is utilized to identify a person or an object by means of radio frequency transmission. It describes a wireless identification technology that communicates data by radio waves. This technology can be used to identify, track, sort or detect a wide variety of objects.

In RFID system communication takes place between a reader (interrogator) and a transponder, often called a tag, where data is encoded in a chip. Tags which are integrated with an antenna and packaged into a finished label, and can be either active (powered by a battery) or passive (powered by the reader field) [16, 17].

Most recently, RFID is gaining importance and popularity in many areas such as supply-chain management [13, 19], marathon races, airline baggage tracking, electronic security keys, asset tracking, electronic tolling for roads, automatic ticketing systems, returnable container tracking, animal identification and tracking, and item identification [13, 19-22]

These capabilities represent some distinctions over previous Auto-ID technologies such as barcodes. These advantages include [23-25]:

- Ability to track assets with *no line of sight* requirements. Hence, there is no need to directly expose labels to readers. RFID technology is able to scan and read from various angles.
- Less labor required as minimum manual intervention.
- Less data collection and entry required.
- More automated reading and improved read rates. Multiple tags can be read rapidly and simultaneously, resulting in faster movement of goods in supply chain and easier tracking of equipment in the facility.
- More timely information for decision making, as RFID is able to track events, people and medical equipment in real-time as they move.
- Flexibility to rewrite and reprogram the tags.
- Ability to store a larger amount of data.
- More robust form factors resulting in increased effectiveness in harsh environments such as temperature extremes, dusty and dirty conditions. So it can withstand chemicals and damages better.
- Improved data accuracy.
- Ability to identify items as unique objects (item-level ID) rather than identifying generically (class-level ID) as in barcodes.

However, there exist some omnipresent limitations to employ RFID technology in a system which can be summarized as [26]:

- RFID tags are expensive compared to barcodes, and implementation costs are still very high.
- Tag and reader incompatibilities still exist between rival manufacturers.

- Large amount of data produced by RFID systems can overload database systems.
- RFID signals are blocked in certain environments such as liquids and metals making it less ubiquitous.

2.5 Need for RFID in healthcare systems

Healthcare is one the most critical sectors in service industry. Since it is life-crucial, any mistake can cause inevitable and incurable results [28]. In such a service industry it is very important to provide the right information at the right time in the right location. Information sharing can play a vital role in improving the system. But we need to build such an information centre that will avoid sharing of wrong/insufficient information. The healthcare industry is taking strong steps towards improving the information system [16]. Through a strong and well accepted information system everyone can be connected and administrative cost can be reduced. There are several obstacles in identifying and tracking objects and people in the hospital environment which bring difficulties to real-time decision making and management [2]. RFID is considered to be the next revolution in the healthcare industry to overcome existing obstacles in information system [19]. The healthcare community can expect tremendous benefits by deploying RFID for item location (especially high-value mobile assets) and security along with maintaining the highest level of data integrity. RFID can be used for door security, patient identification, inventory management, medical file management, pharmaceutical security, high-heat and sterilization tracking, error reduction at point of care, medications management, and real-time asset and employee tracking [6, 23]. To exemplify these applications IBM presents the following: (1) implanting RFID chips inside surgical instruments to ensure that they are not left inside a body after surgery, (2) affixing RFID labels onto surgery patients to confirm their identity and the exact procedure to be performed, (3) tracking the disposal of hazardous medical waste, and (4) tagging patients with RFID chips containing complete medical histories. Another instance of RFID application in healthcare can be tracking newborn babies to prevent mismatching mother and baby when they are separated for needed neonatal care [29]. Apart from these other possible applications include location of staff and patients, theft prevention, patient safety-validation, incident audit trail, dynamic patient-equipment association, equipment status, and cost capture [30].

Many of the processes which are taking place in a healthcare system require time management. It is vital to provide the right resource at the right time in the right quantity. Resources include manpower, materials and information. Usually in hospitals there is large amount of real time inventory in the form of medical equipment, surgical instruments, drugs and even patients, nurses, doctors etc. these can be classified as:

- People: Patients, Doctors, Nurses
- Critical equipment: Medical equipments, Oxygen cylinders etc.
- Other assets: Drugs, Surgical instruments, blood etc.

The dynamics of the healthcare system makes it complicated to locate this inventory when required, because the location of this inventory is constantly changing. The type of resource or treatment required varies for every patient and results in each service provided being unique. It is vital to locate the correct resources when needed and thus requires maximum visibility. Automatic identification technology can help in enhancing the visibility of this real time inventory and can help in quickly locating resources.

RFID technology has begun to interest technology marketplace drivers such as Wal-Mart and Target. The main driver behind this has been the evolution of wireless network technology and its ability to improve visibility in complex systems. The benefits of using RFID in such systems go beyond “inventory management, information accuracy, and reduction in operating cost” [6].

In systems like healthcare we need minimal system errors as the life of a patient may be at stake. In such a system, maximum visibility in resource management can be of critical importance. Failure or delay in locating the resource can result in negative outcomes. RFID can help to avoid such situations by improving visibility and minimizing delays thus resulting in an improved resource management system.

The research in healthcare systems has been governed by simulation studies which are driven by subtle assumptions which cannot be treated as a working template; the complexity and diversities in this system demand more detailed analysis. In such cases a proven technology like RFID can be of great help. In their widely cited scenarios, Wicks et al., (2006) [6] state the current applications and inferences of RFID in hospitals for tracking movable equipments like wheelchairs and stretchers etc., which reduce inventory shrinkage by 10% [6]. Some scenarios show RFID is better applied than barcodes. RFID can be highly effective in applications to ensure correct and safe surgery procedures [31]. Among these uses of RFID systems in healthcare, tracking mobile and high-value medical equipment is a priority for healthcare systems. In some cases hospitals spend over $4,000 per bed because of misplaced equipment each year. RFID systems enable hospitals to track real-time locations of these high-value mobile assets. In emergency situations, nurses can spend less time searching for equipment, materials managers can reduce the amount of unnecessary ordering, and maintenance schedules and sterilization records can be simplified by using rewritable RFID tags [20].

2.6 Sensor positioning system for resource tracking

Many systems need real time tracking of the inventory or assets in a system which is spread out in a large area. Due to the limited read range of the reader in tag-reader communication, the number of readers has to be sufficient to cover the area. Effective network planning can help in optimizing the reader positions [17]. The system is also driven by cost constraints thus the system design should consider optimum number of readers to locate the tags or the real time inventory. In such cases the placement of reader becomes critical.

Location-allocation models deal with the placement of service centers to provide maximum service value to the entire system. Such models can be extremely helpful in healthcare services while planning the service networks to have the demand satisfied in the least amount of time [16]. Network planning in RFID system is governed by antenna positioning. Such planning must also consider the inherent characteristics of RFID systems such as tag type, reader type, communication type (induction or backscatter) and frequency. RFID networks are complicated to design as the identification is governed by the type of system in place [17]. In such designs the sensor field is divided into a grid which represents possible reader locations as shown in Fig 2.3.

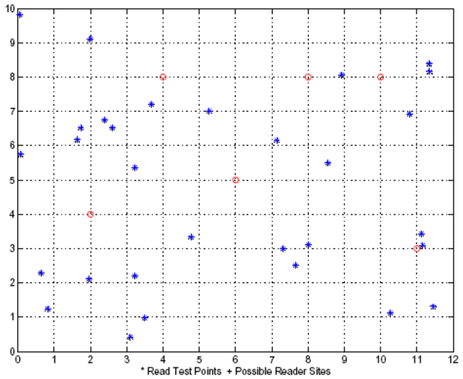


Fig. 2.3
Grid with possible reader points [17]

There is literature which focuses on efficient ways of managing the sensor networks to optimize the power usage at each sensor so that the life of the Gateway (Sensor Network) is optimized [16]. The main focus has been on the ways in which the energy savings can be achieved to optimize power usage; sensors are deployed for particular task and distributed evenly to effectively manage the overall network with minimum energy consumption [16].

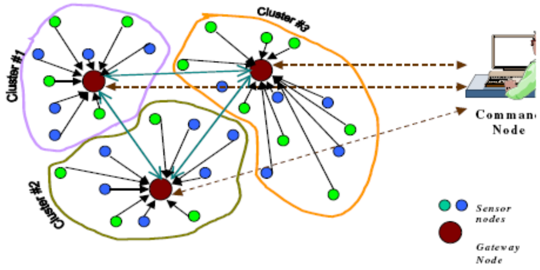


Fig. 2.4
Typical clustered sensor network [16]

As shown in Fig 2.4, the sensor network is based on a number of criteria such as communication range, number and type of sensors, and geographical region [16]. Depending upon the available communication range, various clusters are formed. The basis of allocation is accuracy in transferring the information [16]. The objective function in a clustered network design is always governed by the life or utilization of the sensors where the objective is to make full utilization of the sensors, or gateways [16].

The Maximal Covering Location Allocation Model is a type of location-allocation model, dealing with a fixed service provider who serves a maximum population within a standard distance with all the customers staggered. This is in line with a specific number of readers (service providers) placed in an area who serve (try to locate) the tags (customers). This model tries to maximize the number of tags read by a reader and thus covers the maximum population of tags possible.

The objective here is to place the readers in such a manner that at any point of time all the readers will be able to locate all the tags in their respective read ranges. It has become important to optimize the number of sensors (readers) from an economic standpoint while still achieving the same performance. The main objective of secluding the reader positions is to distribute them evenly and efficiently throughout the system [13, 17].

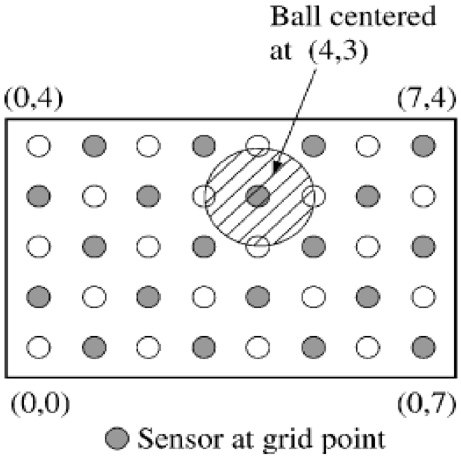


Fig. 2.5
Design of a Typical Sensor Grid [13]

The size of each cluster is governed by the type and read range of the RFID tag. Sensor fields are divided into 2D grids as shown in Fig 2.5 and Fig 2.6. Here the position of the sensor or reader depends on the "communication range, number and location of the reader" [13, 17]. The sensor positions are also affected by the presence of obstacles, metals, rooms, corridors etc. Such kind of sensor placement system design is governed by the type of tag (Active or passive), type of reader, movement of tags, and number of readers. Constraints can also include imprecise detections and terrain properties as well as designer and user preferences [19].

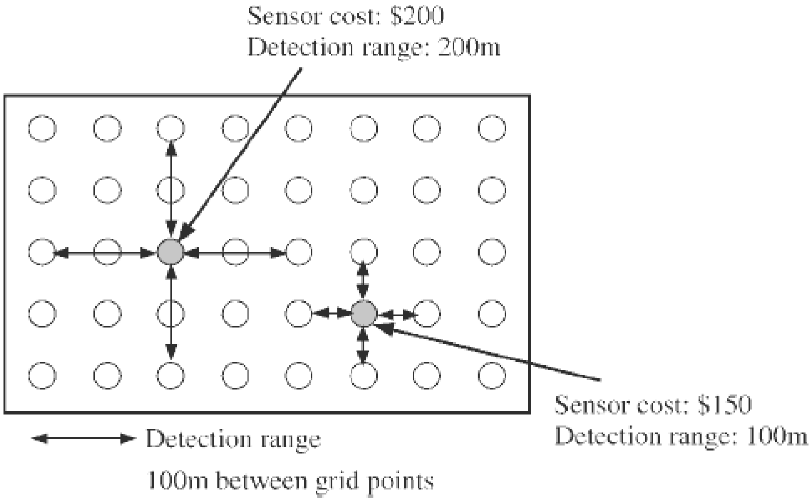


Fig. 2.6
Generic sensor placement design depending on cost and read range [13]

As shown in Fig. 2.6, the area needs to be covered with the sensor and the sensor types governing the economic limitations of such systems. Usually active tags have more read range as compared to passive tags, so they can be identified from a longer distance. It is important to know the dynamics of the system and the possibility that a tag is being located by two readers at a time, known as collision among the two readers. Such collisions can report the presence of the resource in both the grid clusters. Appropriate sensor placement shall avoid such collisions of clusters [13].

2.7 Cost constraint as a driver in an RFID sensor system

Considering cost as the major concern while designing RFID systems, one should be able to determine the system requirements with questions about type of tags, number of readers, reader positions, and cost constraints. Answers to such questions help to define system requirements and enable sophisticated system design. The factors influencing optimizing the number of readers can be cost and network complexity or problems associated with the reader collision which depicts the situation of tags being read by multiple sensors [13, 18]. While optimizing the number of readers, care should be taken to assure that the readers are always in the vicinity of the tags depending on the reader read range [13]. Also the sensor positioning impacts the resource management and a better coordination of backend system with the front end can greatly help the performance of the system [19].

Sensor positioning and optimization has been of interest to researchers who focus on various methods of optimizing and deciding the best sensor places to achieve cost savings. This research uses the location allocation model which is prominently used in network locating or facility locating problems.

2.8 Location Allocation Models

Location-allocation models are the most common models used for facility location problems. These models are divided into two different forms. One is location-allocation models being used for plane locating problems where the system is not a network. The other is the model being used for network locating problems [32]. Location allocation models are used while designing a system in a poor geographical area with less service accessibility [32]. There is considerable evidence that because of poor geographical accessibility, basic health care does not reach the majority of the population in developing nations. Despite the view that mathematical methods of location analysis are too sophisticated for use in many of these nations, several studies have demonstrated the usefulness of such methods in the location decision-making process. So this will be very valuable and useful to review and summarize the use of location-allocation models in location allocation problems [32]. In RFID reader locating problems, readers and tags make a network; the network forms of the location-allocation models will be discussed here. Network forms of the location-allocation models contain *P* facilities and *N* demand nodes and the objective is to locate these *P* facilities between these *N* demand nodes such that a cost function is minimized [32]. Based on the definition of this cost function and the nature of constraints in the model, network forms of the location-allocation models are divided in to four different models:

1. *P*-median problem
2. *P*-center problem
3. Location Set Covering Problem (LSCP)
4. Maximal Covering Location Problem (MCLP)

2.8.1 *P*-center problem: *P* center problem sites *P* facilities using assigning clients such that the maximum distance between client and the facility is minimized. *P* center problems can be regarded as NP hard problems [33]. The mathematical formulation for *P*-center problem is as shown in Table 2.1.

2.8.2 Location set covering problem (LSCP): These models locate the least number of facilities such that each demand node gets covered by at least one facility within a specified maximum distance or time. For the first time, Local Set Covering Problem (LSCP) models was used for an emergency facility location problem; the objective in LSCP models is to locate the least number of facilities that are required to cover all demand nodes [34-36]. The following Table 2.1 lists the formulations for all the models discussed here.

Table 2.1 [36]
Typical Facility location models

Type of model	**Objective function and constraints**	**Meaning of notation**
P-median problem	$Maximize\{Z = \sum_{i=1}^{m} \sum_{j=1}^{n} a_i d_{ij} x_{ik}\}$ Subject to: 1) $\sum_{j=1}^{n} x_{ij} = 1$ for $i = 1,......,m$ 2) $x_{ij} \le x_{jj}$ for $i = 1,....m; j = 1,...n$ 3) $\sum_{j=1}^{n} x_{ij} = p$ 4) $x_{ij} \in \{0,1\}$ for $i = 1,...m; j = 1,...,n$	i = Index of demand points; m =total number of demand points in the space of interest; j = index of potential facility sites; n =total number of potential facility locations; a_i weight associated to each demand point; d_{ij} =distance between demand area i potential facility at j; x_{ij} =1 if demand area i is assigned to a facility at j;

P-center problem	$v(PCP) = \min r$ Subject to: 1) $r - \sum w_k d_{kj} z_{kj} \geq 0$ for $\forall k \in K$, 2) $\sum_{j \in J} z_{kj} = 1$ for $\forall k \in K$, 3) $z_{kj} - y_j \leq 0$ for $\forall k \in K$, $j \in J$ 4) $\sum_{j \in J} y_i = p$ 5) $z_{kj}, y_j \in \mathrm{B}$, $\forall k \in K$, $\forall j \in J$	r = radius or distance between client and the facility k, K = demand points $w_k d_{kj}$ = weighted distance j, J = intersection points or facility points z = decision variable p = facilities to be sited y = decision variable $\mathrm{B} = \{0,1\}$
Location set covering problem	$Min \sum_{j \in N_i} x_j$ Subject to : 1) $\sum_{j \in N_i} x_j \geq 1 \quad \forall_i \in I$ 2) $x_j \in \{0,1\} \forall_i \in J$	i, I = the index and set of demand points and nodes; j, J = the index and set of eligible facility sites or nodes; d_{ij} = the shortest distance or time between points or nodes i and j ; S = a distance or time standard; a facility sited at some node j within the standard of a demand node i is eligible to serve the demand node; N_i = $\{j \mid d_{ij} \leq S\}$ is the set of nodes j within distance or time S of node i ; these nodes are the nodes eligible to house facilities which “cover” node i ; $x_{ij} \in \{0,1\}$. It is 1 if a facility is sited at j , and 0 otherwise.

Maximal covering location problem	$Max\sum_{i\in I} a_i y_i$ Subject to: 1) $y_i \le \sum_{j\in N} x_j$ for $\forall_i \in I$ 2) $\sum_{j\in J} x_j = p$ for $y_i and x_j \in \{0,1\}$ $\forall_i \in I, j \in J$	i, I = the index and set of demand points and nodes; j, J = the index and set of eligible facility sites or nodes; a_i = the population at demand node i; p =facilities to be sited; $y_i \in \{0,1\}$. it is 1 if demand node i has one or more facilities sited within S distance units, and 0 otherwise; $x_j \in \{0,1\}$ = is a decision variable if a reader is located in reader node j it is "1" otherwise it is "0".

2.8.3 *P*-median problem: The main objective in *P*-median problem models is to locate *P* facilities (servers) between *N* demand (customer) nodes such that the average distance between servers and customers is minimized [35, 36]. The *P*-median models concentrate on optimizing the overall (or average) performance of the system. But the *P*-center model attempts to minimize the worst performance of the system. Thus in these models, service inequity is more important than average system performance. In location literature, the *P*-center model is also called "Mini max" model because it minimizes the maximum distance between any demand node and its nearest facility [35, 36]. The mathematical formulation for *P*-median problem is shown in Table 2.1.

2.8.4 Maximal covering location problem (MCLP): Church and ReVelle (1974) and White and Case (1974) developed the Maximal covering location problem (MCLP) model in which it is not necessary to completely cover all demand nodes [35, 36]. Instead, the objective in these models is to maximize coverage of demand nodes with a given number of facilities [35]. The maximal covering location problem (MCLP) can be regarded as a special case of a LSCP problem where LSCP sites the minimum number of facilities needed to cover all demand nodes under a specific distance. MCLP considers a case where resources are limited and cannot cover all the demands [36]. The concept of coverage remains the same as P demand nodes getting covered by N facilities. But the aspect of probability predicts that all demand nodes are not covered and the system needs to have other heuristics as well [36]. MCLP can be very well applied for the system where limited coverage is sufficient and cost constraint must be satisfied. The MCLP model best fits the objectives of the proposed research.

2.9 Discrete cosine transform and sensor fields

Discrete cosine transform (DCT) is a special case of discrete Fourier transform which contains only the cosine components. DCT is extensively used in image compression where an image is considered to be made up of small “sub-blocks” for processing [9]. This property of DCT makes it useful in image processing for encoding a highly correlated image and converting it into more compact form [11]. DCT attempts to de-correlate the signal data by reducing the redundancy between the pixels to analyze each pixel separately [8]. DCT is most powerful as compared with the other types of transforms while de-correlating the image pixels [8]. The main purpose of de-correlation is to analyze the image on a pixel level where the adjacent pixels exhibit similar properties or in other words high correlation. The correlations can be used to calculate the value of the pixel. Applying DCT to an image converts the correlated pixels in to de-correlated ones to analyze each pixel separately.

One dimensional DCT: [10]

1-D DCT of a real valued signal $x(n), n = 0,1,....N-1$ is defined as

$$X_{ct}(k) = C(k)\sum_{n=0}^{N-1} x(n)\cos \pi / 2N(2N+1)k \qquad k = 0,1,....N-1$$

1-D inverse DCT is given by [10]

$$x(n) = \sum_{k=0}^{N-1} C(k) X_{ct}(k)\cos \pi / 2N(2n+1)k \qquad n = 0,1,....N-1$$

Where

$$C(k) = \sqrt{1/N} \qquad \mathit{for} \quad k = 0$$

$$C(k) = \sqrt{2/N}\cos\left[((2j+1)i\pi)/2N\right] \qquad \mathit{for} \quad k = 1,2,3....N-1$$

Two dimensional DCT [10]

2-D DCT of a real valued signal $x(n_1, n_2), n_1, n_2 = 0,1,....N-1$ is given by

$$X_{ct}(k_1,k_2) = C(k_1)C(k_2)\sum_{n_1=0}^{N-1}\sum_{n_2=0}^{N-1} x(n_1,n_2)\cos \pi / 2N(2n_1+1)k_1 \times \cos \pi / 2N(2n_2+1)k_2$$

where,
$k_1, k_2 = 0,1,...., N-1$

2-D inverse DCT is defined as [10]

$$x(n_1,n_2) = \sum_{k_1=0}^{N-1}\sum_{k_2=0}^{N-1} C(k_1)C(k_2)X_{ct}(k_1,k_2)\cos \pi / 2N(2n_1+1)k_1 \times \cos \pi / 2N(2n_2+1)k_2$$

where
$n_{1,}n_2 = 0,1,...N-1$

2D- DCT is extensively used in image compression where we want to represent or store the image with minimum information associated with it. Properties of DCT such as de-correlation, separability and energy compaction make it very useful in the image processing environment. Applying 2D- DCT involves developing an algorithm where the data in the form of pixels is first partitioned and arranged properly and the subsequent steps follow thereafter [11].

In a case where the corresponding pixels in an image interact or compensate for each other's motion, they share even amount of energy or power or information required to describe the overall image. In this case the total energy or information required to depict the image is greater as compared to uncorrelated pixels which do not compensate for each other [8].

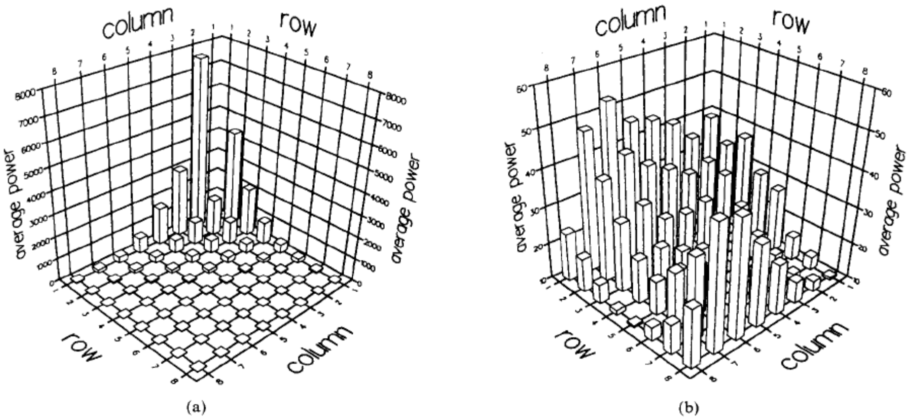


Fig. 2.7
Pixels power distribution depending on motion compensation [8]
a) uncompensated pixels b) compensated pixels

The pixels in Fig. 2.7 (a) show more power in the corner as a result of the normalization process applied where Fig. 2.7 (b) has even power distribution as a result of motion compensation [8].

The important property of DCT is that it associates the frequency information with the pixels by associating its individual signal property.

Properties of DCT:

Properties of DCT have been used to filter the pixels depending on the frequency domain that they belong to and the relations between the pixels are developed [9]. The DCT filtering relationships are useful in reducing the noise associated with the image and eventually for enhancing the image [9]. This section will reveal various properties of DCT which are extensively used in image processing.

- *Separability:* DCT can be applied to the image in x-axis and in y-axis separately [11]. Then the two axes can be combined to analyze the overall image. This increases flexibility but the computation time takes longer than applying the 2D- DCT where the two parts take care of the respective axis as depicted in the 2D- DCT [11].
- *De-correlation:* De-correlation helps in removing the redundancy between the adjoining pixels. This means each pixel is separated from its correlated or de-correlated adjoining pixel for analysis. DCT is powerful in analyzing the de-correlation properties of an image.
- *Energy compaction:* Using the correlation property and discarding the low value pixels from the image and reforming it uses less energy to depict the overall image. Here DCT uses the correlation property to come up with the energy of the correlated pixels and de-correlated pixels.

Applying DCT to an image:

Input for DCT is an 8 by 8 matrix which contains the information about each pixel in the form of an integer value of the signal. This DCT is known as 8 point DCT [37]. The transformation matrix is given as follows [38].

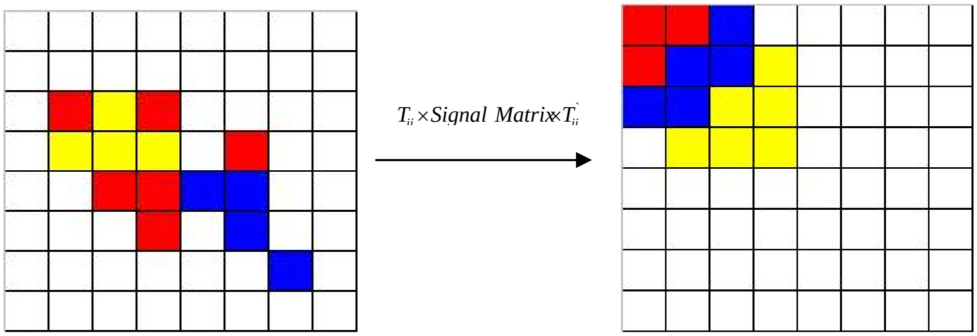
$$T_{ij} = 1/\sqrt{N} \qquad\qquad if\ i = 0\ |$$

$$T_{ij} = \sqrt{2/N}\cos\left[((2j+1)i\pi)/2N\right] \qquad if\ i > 0\ |$$

Where T_{ij} is the transformation matrix which is constant for every DCT transformation and N is the size of the transformation matrix. In the case of an 8 by 8 matrix N is equal to 8 [38]. This matrix is called an orthogonal DCT matrix as when we perform DCT on any image when we need that image to be a lossless function. DCT on 8×8 block is given by [38]

$$\text{DCT transformed matrix} = T_{ij} \times Signal\quad Matrix \times T_{ij}^{`}$$

This transformation is called applying DCT to a signal or the 8×8 pixel sized matrix.



Signal Matrix

DCT transformed signal matrix

Fig. 2.8
Applying DCT on image for energy compaction [39]

Fig. 2.8 depicts the transformation of an 8 by 8 pixel sized matrix on an image after applying DCT. The Red-Blue-Yellow colors depict the intensity of the signal with red having the highest intensity, or more information, as compared to blue and eventually yellow. The transformation results in the accumulation of the overall signal information getting stored in the left corner with highest intensity in the corner decreasing from top to bottom and left to right [38]. This is repeated for the overall image and results in the energy compaction of the total signal information. Being a lossless function, the total information after transformation is the same as the total information before the DCT transformation [38].

CHAPTER III

PROPOSED METHODOLOGY

This chapter explains the proposed methodology and procedure to design an RFID sensor system with a user driven sensor approach from a resource perspective. The research method applied here was chosen after discussions with hospital personnel at Stillwater Medical Center and was modified as per hospital regulations and policies. The design assumes the existing RFID system will remain using the same number of RFID sensors to comply with budget constraints. Under such a scenario, rather than minimizing the number of readers, the primary optimization problem is to effectively place a limited number of RFID readers so as to maximize the system sensor field coverage. This section proposes a model to handle such a case.

The present discussion focuses on RFID sensor positioning for efficient asset tracking which can be effectively achieved using a maximal covering location problem. Therefore, this thesis focuses on optimal RFID reader placement to track crucial assets using an improved maximal covering location problem (MCLP) enhanced with criticality index analysis exemplified in a healthcare facility. Crucial assets can be defined as the resources which are costly and are few in quantity. In case of emergency, it is vital for healthcare staff to easily and quickly locate them.

Fig. 3.1 summarizes the general framework of the proposed methodology. First, severity analysis of the assets to be tracked will be performed based on a Likert scale.

Then the whole floor plan of the healthcare facility will be divided into squares as a representation of grid points. By performing the frequency and dwell time analyses for each square and combining them with severity analysis, the criticality index of each square can be evaluated.

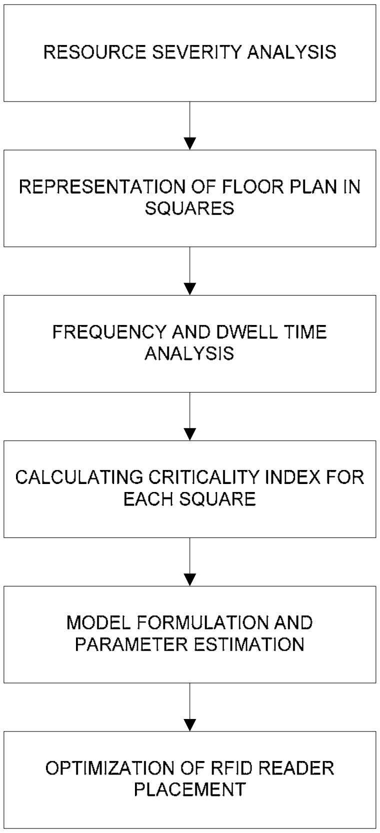


Fig. 3.1
Flow chart of procedure of proposed methodology

3.1 Resource severity analysis

As the RFID system under design is resource focused, the resource severity analysis will be used. This includes study of the resources being allocated for a specific purpose. It will include conducting interviews with hospital personnel to gather information regarding resources they think is most important and those they have trouble in quickly finding it in emergency situations. We will mark the importance of that resource severity on a Likert scale.

Severity (S_k): The importance level of asset *k* in emergency cases evaluated based on a Likert scale.

3.2 Representation of floor plan in squares

The first step in our proposed method is to divide the whole floor plan into small squares as seen in Figure 3.2. The floor can be considered as a grid that contains *n* squares called *demand squares (DS)* in a MCLP.

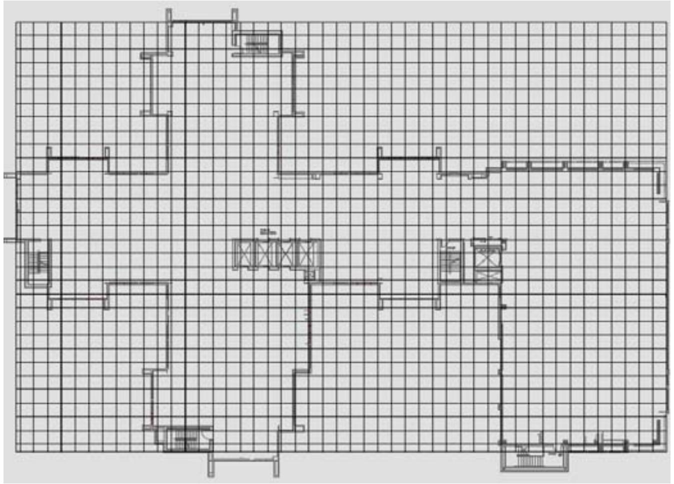


Fig. 3.2
A floor plan representation divided into grid of squares

As seen in Fig. 3.3, a *reader* node “A” in the circle is defined as a candidate place for the RFID reader which covers its surrounding demand squares based on its radius of reader range (RRR). Four demand squares are represented in Fig. 3.3 as an example. However, by dividing the floor plan into different number of demand squares and considering various read range of RFID readers, the coverage of a reader node may vary.

3.3 Frequency and dwell time analysis

In order to evaluate the possible position of RFID sensor placement a frequency and dwell time analysis helped to investigate the movement of the critical assets in the hospital facility. The parameters are defined as follows:

Frequency (f_{ki}): Number of times asset *k* passes through demand square *i* in a day.

Dwell time ($(d_t)_{ki}$): Average of time *t* that asset *k* spends in demand square *i* in a day.

3.4 Calculating criticality index for each square

In order to evaluate the reader coverage achieved after positioning a reader on a particular reader node, it is necessary to evaluate *criticality index* of the demand squares which it covers. It is proposed here to evaluate the criticality index of these squares by integrating *severity*, *frequency* and *dwell time* of all assets which visit that particular demand square.

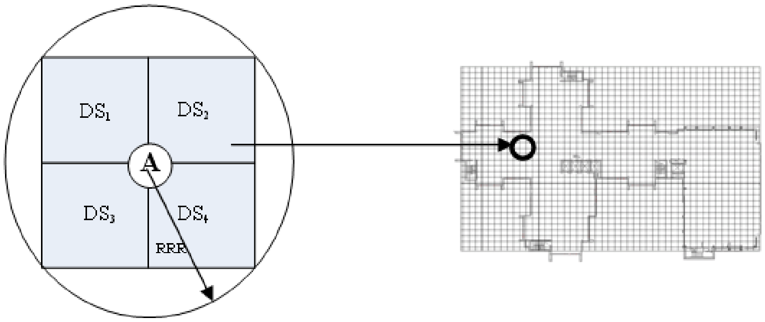


Fig. 3.3
Reader node and the demand squares

The criticality index of demand square *i* which is represented by c_i is calculated using the following equation:

$$c_i = \sum_{k=1}^{L} f_{ki} * (d_t)_{ki} * s_k$$

Where,

k = type of assets from 1 to L

f_{ki} = frequency of asset k in square i per day

$(d_t)_{ki}$ = dwell time t of asset k spent in demand square i per day

s_k = severity of asset k

A greater criticality of a demand square means either a higher frequency of asset visits to that particular demand square (referring to frequency), or a larger amount of time spent in that demand square (referring to dwell time), or the more critical assets are being utilized/stored in this demand square (referring to severity of asset). A square is referred to as a demand square which demands coverage by a sensor.

By considering Fig 3.3, coverage of reader node A is given by the addition of the criticality indices of demand squares that it can cover based on its read range. Namely the coverage will be A = $c_1 + c_2 + c_3 + c_4 + \ldots\ldots + c_t$ under the assumption that one reader can cover t number of demand squares.

3.5 User Driven Calculation of Criticality Index

The methodology proposed for the Stillwater Medical Center is constrained for a specific number of readers. This section looks at the flexibility aspect from the system design standpoint where the user can drive the system by incorporating or changing the parameters according to needs. Thus the system designed above is modified from the user's perspective while designing the system. Here we will look at two aspects as follows,

1. User defined criticality index parameters

2. User defined number of RFID readers

Now we will look at these two aspects one by one

User defined criticality index: We will redefine the criticality index for reference

$$c_i = \sum_{k=1}^{L} f_{ki} * (d_t)_{ki} * s_k$$

Where,

k = type of assets from 1 to L

f_{ki} = frequency of asset k in square i per day

$(d_t)_{ki}$ = dwell time of asset k spent in demand square i per day

s_k = severity of asset k

Here all the three parameters are considered while calculating the criticality index. But if the user wants to consider only one or a combination of two of the parameters, this will be incorporated as well while designing the sensor system. This gives the user more options to set parameters for the severity, frequency and dwell time

Table 3.1: User defined criticality indices

Definition of Criticality index (CI)	**Formula for the criticality index**
CI based on severity	$C_i = \sum_{k=1}^{L} s_k$
CI based on frequency	$C_i = \sum_{k=1}^{L} f_{ki}$
CI based on dwell time	$C_i = \sum_{k=1}^{L} (d_t)_{ki}$
CI based on severity and frequency	$C_i = \sum_{k=1}^{L} s_k * f_{ki}$
CI based on severity and dwell time	$C_i = \sum_{k=1}^{L} s_k * (d_t)_{ki}$
CI based on frequency and dwell time	$C_i = \sum_{k=1}^{L} f_k * (d_t)_{ki}$

The Criticality indices calculated using above definitions are used to design the separate sensor field for each scenario. The user can analyze the sensor field for the respective scenarios and can apply the sensors depending on the requirements of that particular scenario.

3.6 Proposing a maximal covering location allocation model for sensor positioning

After calculating the criticality index for each square, sensors will be placed to serve squares with high criticality indices. The floor plan is divided into small squares assuming that a sensor covers particular number of squares. To design the sensor field the number of sensors shall be optimized depending on the sensor type. These factors are considered in designing a schematic of the mathematical model as shown in Fig. 3.4.

In this schematic, the number of sensors is shown as a constraint. As not all the squares have high criticality indices, there is no point in putting sensors where the squares have low criticality indices or there is a low possibility of an asset being located in those squares. The model is also governed by the read range of the sensor. As the sensor with longer read range is automatically going to govern the number of sensor in the sensor field. Fig. 3.4 illustrates the inputs, outputs and constraints of our mathematical model.

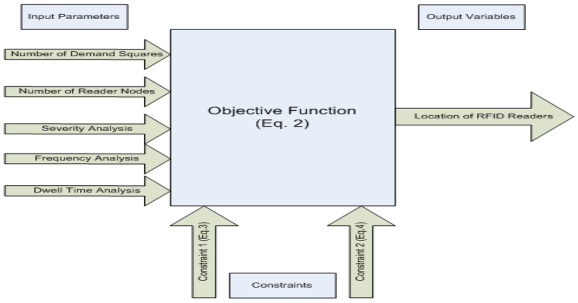


Figure 3.4
Schematic representation of model

Having a fixed *p* number of readers the objective is to maximize the possible coverage of readers by locating these *p* readers on *m* candidate reader nodes. The mathematical formulation of the above schematic model is as shown below

$$Max \;\; w_1(\sum_{i=1}^{n} c_i y_i) - w_2 \sum_{i=1}^{n}((\sum_{j \in N_i} x_j) - y_i)$$

$$S.T$$

$$\sum_{j \in N_i} x_j \geq y_i \qquad for \quad i = \{1,2,...,n\} \quad where \quad N_i = \{j \mid d_{ij} \leq s\}$$

$$\sum_{j=1}^{m} x_j = p$$

$$x_j = 0,1 \qquad j = \{1,2,...,m\}$$

$$y_i = 0,1 \qquad i = \{1,2,...,n\}$$

$$w_1 \leq 1$$

$$w_2 \leq 1$$

$$w_1 + w_2 = 1$$

Where c_i is the criticality index of each demand square in the grid, y_i is a binary variable whose value is “1” if demand square *i* is covered by at least one reader and “0” otherwise. *n* is the total number of demand squares, and *m* is the total number of reader nodes (candidate places for readers). x_j is a binary decision variable whose value is “1” if a reader is located at reader node *j,* and “0” otherwise. Therefore, y_i is dependent on x_j. N_i is the set of reader nodes *(j)* that can cover demand square *i*. This fact brings the requirement that the distance between these reader nodes *j* and demand square *i* “l_{ij}” be less than the read range of the reader “s”.

The objective function of this model is to identify the optimal location of available readers by: (1) maximizing total covered criticality indices of demand squares by $(\sum_{i=1}^{n} c_i y_i)$ and (2) minimizing the reader collision by $(\sum_{i=1}^{n}(\sum_{j \in N_i} x_j) - y_i)$. The first objective is clear but the second objective requires further explanation: Since the model can assign more than one reader that will cover the same demand square(s) reader collision may occur. To minimize this possibility of reader collision, the second objective will force the model to assign only one reader for the same demand square to be covered. These two objectives are formulated as a multi-objective function in which the importance of each objective is represented by two different weights, namely w_1 and w_2.

By having at least one reader on one of the elements of N_i $(\sum_{j \in N_i} x_j \geq 1)$, demand square i will be covered $(y_i = 1)$. On the other hand, demand square i will be an uncovered square $(y_i = 0)$, if there is no reader on N_i reader nodes $(\sum_{j \in N_i} x_j = 0)$. This constraint is formulated in the mathematical model. The constraint indicate that the total number of available readers is fixed at p is represented in the model. Fig 3.4 illustrates the input parameters, output variable and constraints of the developed optimization model.

This model is very similar to a maximal covering problem model in which the objective is to maximize the coverage of a serving system (in this case RFID readers). As the sensor system being built is specific to the RFID environment, which has unique properties, there are major differences between the typical maximal covering model and the model which is being used. The differences are due to two properties of the RFID system:

1. Readability: a tag is read by the reader in its read range

2. Collision among multiple readers: a tag is read by multiple readers

If the distance between the demand node (square) and the server node (reader) is less than a threshold (read range of reader) then it will be served (read) automatically and no decision variable is needed for that particular demand node (square) to be served (read) or not. The following constraint is incorporated to address this situation:

$$\sum_{j \in N_i} x_j \geq y_i \qquad for \quad i = \{1,2,...,n\} \quad where \quad N_i = \{\, j \,|\, d_{ij} \leq s\}$$

This constraint resolves the readability constraint.

The collision factor is resolved in the objective function itself. The mathematical formulation is given as follows. It consists of objective function and the constraints.

RFID system with flexible readers:

The model developed above is designed for a specific number of readers limited by budget constraints. If the RFID system is not governed by budget constraints, flexible number of readers applied to maximize the coverage of the system, up to 100 % coverage. To revise the proposed mathematical model for flexible readers, the parameter p is replaced by m while keeping the other parameters the same.

$$Max \ w_1 (\sum_{i=1}^{n} c_i y_i) - w_2 \sum_{i=1}^{n} ((\sum_{j \in N_i} x_j) - y_i)$$

$$S.T$$

$$\sum_{j \in N_i} x_j \geq y_i \qquad for \ \ i = \{1,2,...,n\} \ \ where \ \ N_i = \{\, j \,|\, d_{ij} \leq s\}$$

$$x_j = 0,1 \qquad j = \{1,2,...,m\}$$

$$y_i = 0,1 \qquad i = \{1,2,...,n\}$$

$$w_1 \leq 1$$

$$w_2 \leq 1$$

$$w_1 + w_2 = 1$$

Using this model we can design an RFID system for flexible readers. Here the user will enter the number of readers and the model will return the reader position of the readers on the sensor field.

Benefits and drawbacks of the proposed methodology

The proposed methodology proposes benefits and drawbacks as stated below:

Benefits:

- User driven parameter and reader selection
- Optimized position of RFID readers
- Analysis of coverage trend for all the parameters

Limitations:

- Not suitable for large grid size
- Excessive manual calculation involved in calculation of criticality index
- Criticality index calculation is time consuming process

3.7 Applying DCT for calculating the criticality index of squares:

This section discusses the limitations of the proposed methodology and use of discrete cosine transform (DCT) for fast evaluation of the criticality index. The discussion is focused on use of DCT properties for fast evaluation of criticality indices of large sized and complex grids which can save computation time in the calculation of criticality indices.

The criticality index calculation for the each square can be a very complex and time consuming process in cases where the grid size is large. Thus a fast criticality index calculation process is needed where one can more efficiently determine what the probable sensor positions could be, by looking at the traffic of the assets. For calculating the weights of the squares, or the index of the squares, in a grid, discrete cosine transform can be a very powerful tool to de-correlate the squares with low criticality indices from the squares with high criticality indices.

The criticality index is used to incorporate the three parameters of frequency, dwell time and asset severity.

The definition of the three parameters is:

1. Frequency: Traffic or flow pattern of the assets
2. Dwell time: Temporary storage location
3. Severity: Storage location

The value of these parameters used in calculating the value of the square depends on the type of the asset and all the information associated with it. DCT has two powerful properties as discussed in the literature review.

1. De-correlation
2. Energy compaction

We will use these two properties extensively in comparison with the other DCT properties to modify the flow chart given for the DCT transformation for the problem under discussion. Fig 3.5 shows the flow chart for calculating the probable sensor positions.

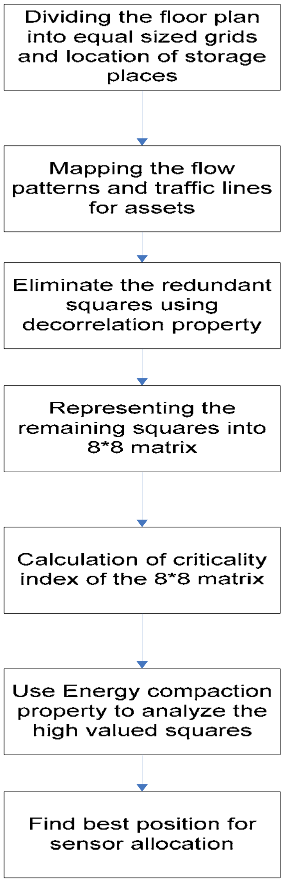


Fig. 3.5
Flow chart for the proposed methodology of implementing DCT

Step 1: The floor plan under the sensor field design will be divided into equal size squares. These squares represent the pixels of the images in a normal discrete cosine transform. These pixels represent the squares of the floor. The size of each square is governed by the read range of the reader; the greater the read range, the coarser the grid, the lesser the read range the finer the grid. After representing the floor plan in the form of squares the storage locations of the assets will be marked on the floor plan.

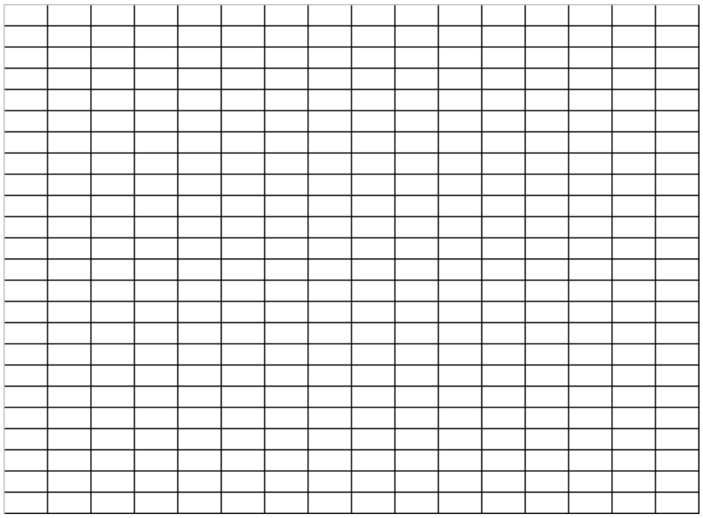


Fig. 3.6
Representing the floor plan in the form of grid

Step 2: The flow patterns for the assets will be mapped on the floor plan through corridors and related areas on the floor to estimate the possible travel paths of various assets on the floor plan starting from their storage locations.

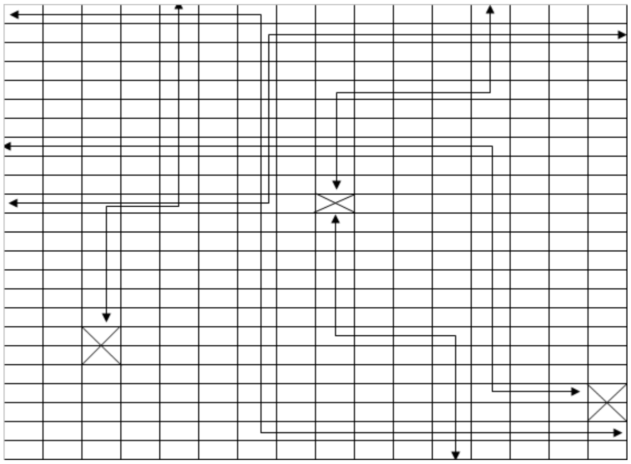


Fig. 3.7
Mapping the flows and storage location of the assets

Step 3: After mapping the traffic paths of all the assets, the de-correlation property of DCT will be applied to remove the redundant squares. Redundant squares are those squares which have no assets traveling through them distinguishing squares on the basis of their criticality index value.

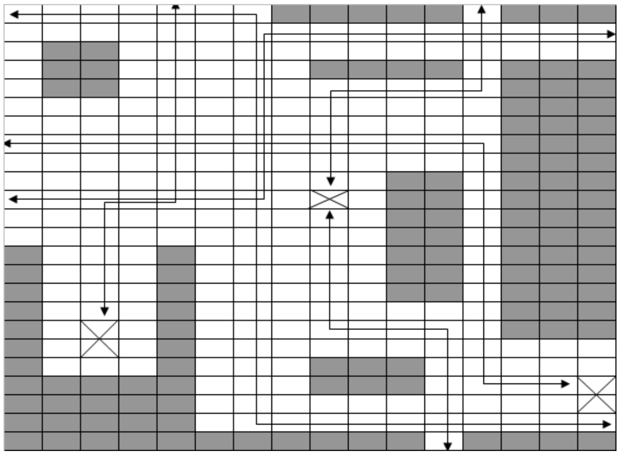


Fig. 3.8
Elimination of the redundant squares

Step 4: The remaining squares, those with assets flowing through them, will be analyzed block by block. Each block will be considered equivalent to an 8 by 8 matrix which will have the value of one square. With the grid divided into matrices each matrix will be analyzed separately.

Step5: Calculation of values of squares involves various sub steps as explained below. We consider the 8 by 8 matrix, similar to a signal matrix in case of image processing, and analyze which assets are visiting that matrix. Depending on the severity and visiting frequency of an asset to a particular matrix the value of each square of that matrix is calculated. The highest valued square will become the candidate position for the sensor.

Step 6: Storage locations have the fixed values governed by the severities of the assets which are stored in them. Same is the case for temporary storage locations.

Depending on the value and severity of the assets stored there, a storage location can be evaluated for sensor placement.

Step 7: Step 7 analyzes the matrix values and applies the “Energy Compaction” property of DCT. The matrix values are plotted on a three dimensional plane. Squares with low values are eliminated while high valued squares are considered as candidates for the reader position.

Two important properties of DCT, de-correlation and energy compaction, are used to analyze the squares similar to the analysis of pixels in of image processing. Comparison of the square value matrices and values of the elements decide the reader positions.

In cases where an asset visits multiple locations it is assumed that whenever there is a split, there is a 50% reduction in the value of the asset. Hence we assume that when visiting different areas of the facility an asset loses its value every time there is a split, or an asset travels in multiple directions.

CHAPTER IV

IMPLEMENTATION OF THE PROPOSED METHODOLOGY AND CASE STUDY

4.1 Introduction of the Healthcare Facility

In order to validate the proposed methodology, a case study is performed at Stillwater Medical Center (SMC). SMC has had an RFID system in place for three years to track the location of certain assets. The assets which are important and/or difficult to find are affixed with active RFID tags so that in emergency situations these assets can be located quickly. However, SMC still faces problems with the ability to locate those assets on time. The reason for this is twofold: (1) There are a limited number of RFID readers so a full coverage of the floor cannot be achieved, and (2) The locations of these readers may not be optimized. The readers were placed based on the experiences and estimation of the healthcare providers in SMC.

To demonstrate the proposed method, the third floor is evaluated in the case study since it was one of the busiest floors. As illustrated in Fig. 4.1, there are three departments on the third floor: (1) Intensive Care Unit (ICU), (2) Respiratory and (3) Nursing.

The assets are stored in various local and central storage places according to the convenience and usability of those assets. The location of these storage places is necessary when the frequency and dwell time analyses are conducted.

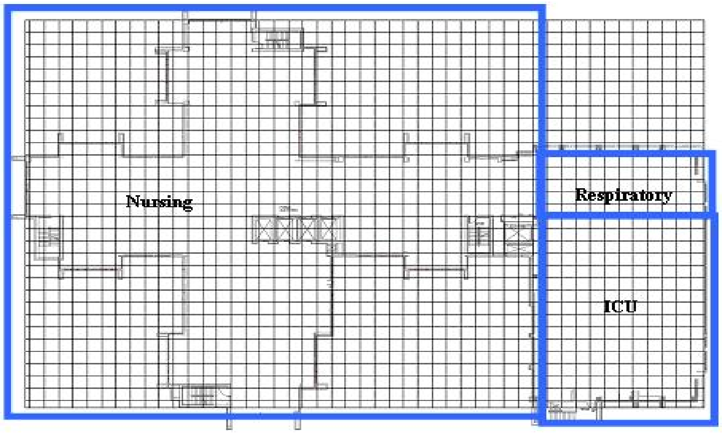


Fig. 4.1
Plan for 3rd floor with its departments

4.2 RFID Tracking System in Use: GE Intellimotion Tracking System

The RFID system being used by SMC was provided by WhereNet Corporation. RFID readers are located on all floors of the hospital. The system consists of the following components: (1) whereport, (2) location sensor, (3) backend application, and (4) tags.

Whereports

In this system RFID readers are called as whereports. When a tag is in the read range of a whereport, the tag is sensed and located by the whereport through certain actions like blinking, on-off etc. The whereport creates a spherical magnetic field which interrogates the tag in its sensing field. Typical read range at various positions with the combination of power requirement and power level settings are given in Table 4.1. The red outlined rectangle in Table 4.1 indicates the read range under optimum power usage. In general, the wider the read range, the greater the required power. The typical practice is to keep the power range at level 4 which gives spherical read range of 7 ft.

Location sensors

Location sensors are the devices which receive a signal from the whereports and then transmit it to the backend application. These sensors communicate with the whereports in their surrounding area. The real time locating system (RTLS) operates on 2.4 GHz RF and the location sensor read range is approximately 350 ft.

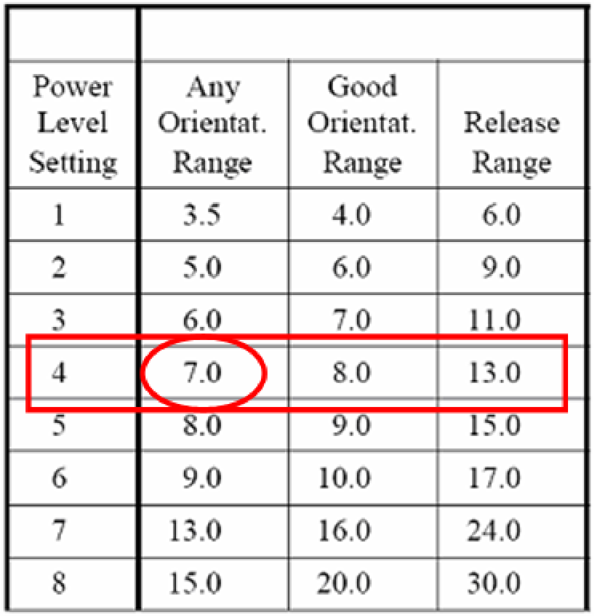
Tags

The system uses active RFID tags. The positioning of these tags is such that they are unobstructed to whereports at all directions. This enhances the signal exchange between the whereport and the tag.

Backend application

The system uses GE IntelliMotion for tracking backend database. This system is mainly used for visualizing the location of an asset at a specific time.

Table 4.1 Various ranges of whereports



Power Level Setting	Any Orientat. Range	Good Orientat. Range	Release Range
1	3.5	4.0	6.0
2	5.0	6.0	9.0
3	6.0	7.0	11.0
4	7.0	8.0	13.0
5	8.0	9.0	15.0
6	9.0	10.0	17.0
7	13.0	16.0	24.0
8	15.0	20.0	30.0

The present sensor distribution and coverage offered by these readers are illustrated in Table 4.1. Since the location sensor offers coverage of about 350 ft. in radius whereas the whereports offer coverage of about 7 ft., the main problem of low RFID system performance stems from the position of the whereports rather than the position of the location sensors. Current location of whereports and location sensor is shown in Fig. 4.2.

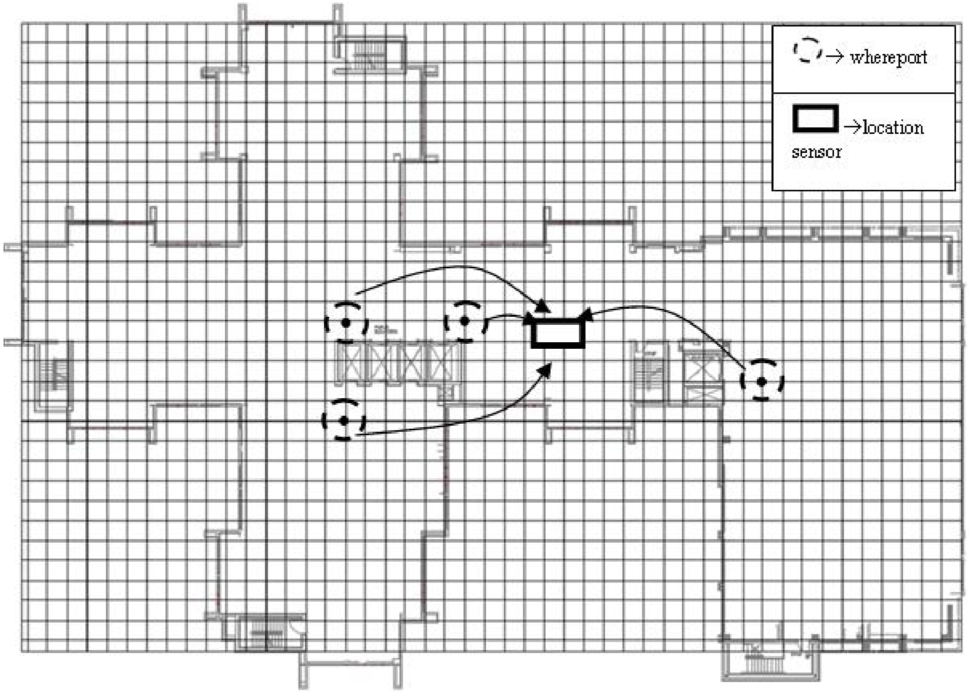


Fig. 4.2
Present Whereport and location sensor placement

4.3 Implementation of RFID Reader Placement Model

a) Severity Analysis of Assets

SMC has several assets which are inadequate in quantity but important in emergency situations to be located on time. These assets are already affixed with active RFID tags and the ones that are used on the third floor are listed in Table 4.2. A survey was conducted with various departments regarding the importance of each asset as defined in Section 2.1. The severity value indicates the degree of importance it has in rescuing the life of a patient, which translates to the degree of importance placed on the ability to locate the asset in a timely manner. The severity values for the assets are shown in Fig. 4.3 in the form of graphical representation.

Table 4.2 Asset information

Name of the Asset	**Owning Department(s)**
Bed Warmer	ICU
CPM Machine	ICU
Doppler	ICU
ECG/EKG Machine	ICU
Heat Therapy Pump	Nursing
O_2 Regulator	ICU, Respiratory, Nursing
PCA Pump	ICU, Nursing
Sequential Compression Pump	ICU, Nursing
Vital Sound Monitor	ICU
Bi-PAP	Respiratory
Wheel Chair	ICU, Respiratory, Nursing
Ventilator	Respiratory
Continuous Pulse Oxymetry (CPO)	Respiratory
IV Pumps	ICU
Entreal Feeding Pump	ICU
Mist tent	Respiratory
O_2 Cylinder	ICU, Respiratory, Nursing

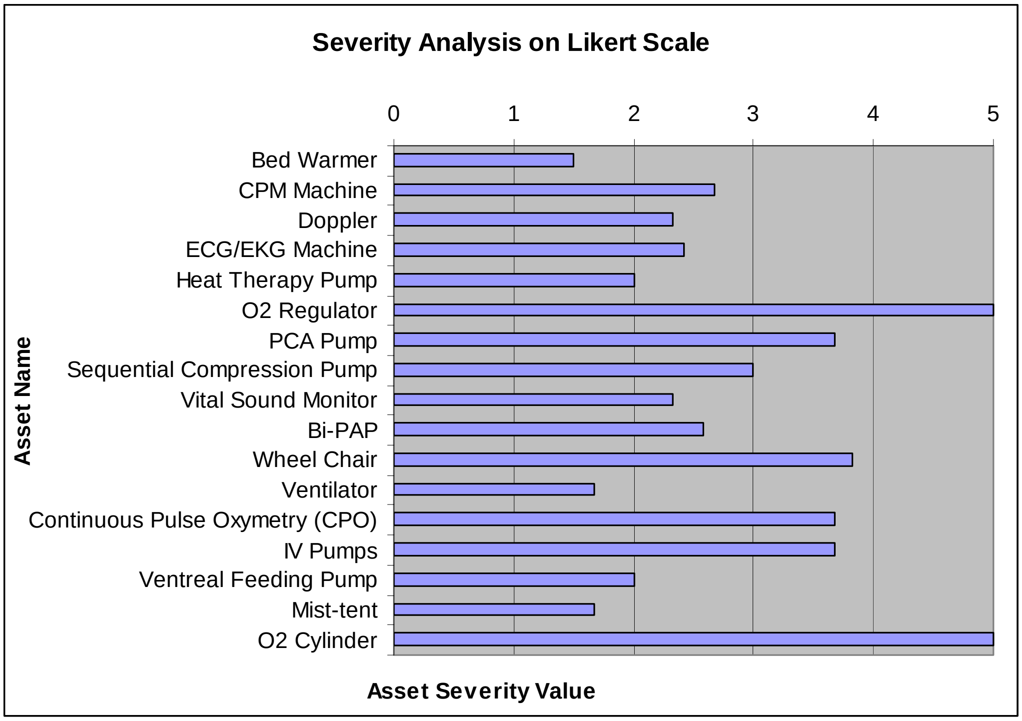


Fig. 4.3
Severity analysis on a Likert scale

b) Frequency and Dwell Time Analyses

Time and motion analyses were conducted for the assets on third floor to identify the path that each asset follows and the frequency it passes through the path per day. These values are assigned as the frequency value, f_{ki} namely, number of times asset k passes through demand square i per day. The asset flow on third floor along with the physical layout is illustrated in Fig. 4.4 which includes main and local storages for the assets, the treatment rooms in which they are utilized, and also the corridors through which they pass. The dwell time is the time that an asset spends in a demand square per day. In a similar process as in frequency analysis, dwell time for each asset was also obtained.

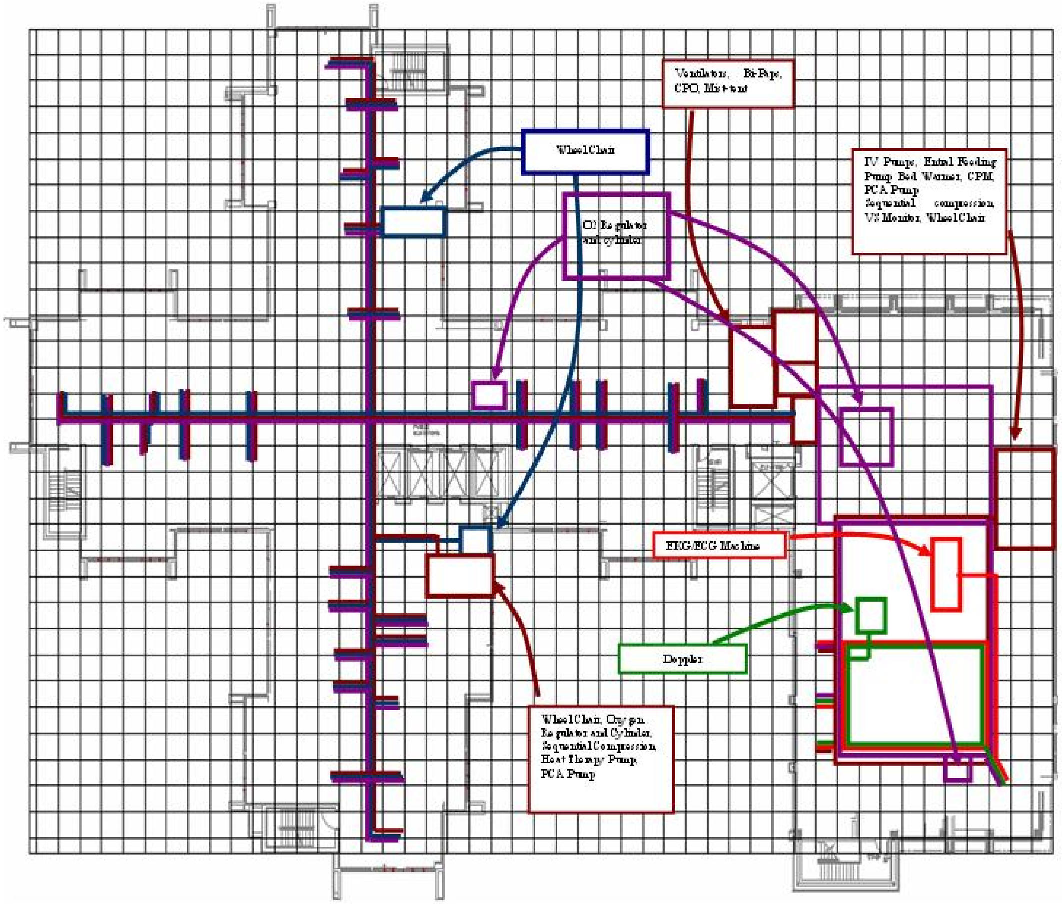


Fig. 4.4
Physical layout explaining the flow of assets on 3rd floor

c) Calculating the Criticality Index of Each Demand Square and Initial Solution

The criticality index of each demand square was calculated as shown in Fig. 4.5 which is the image of third floor plan. It shows different criticality index values of different demand squares with red corresponding to the highest criticality value and blue to the lowest value. Since there are four readers to be used for this floor, the initial solution of reader placement is indicated by circles in Fig. 4.5.

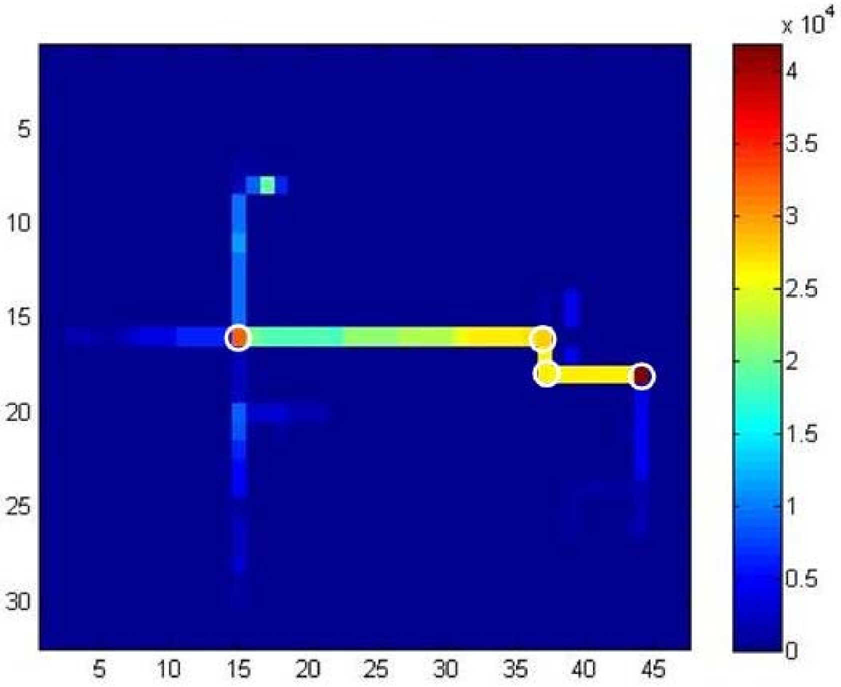


Fig. 4.5
Colored zones of floor plan indicating the criticality of each demand square

4.4 User driven reader allocation

The criticality index been calculated considering all three parameters: severity, frequency and dwell time. These parameters ideally cover all iterations and storage possibilities of a particular asset under consideration. But if the user wants to design the system depending on selected parameters the system should allow for such changes. The following subsections depict the various combinations of the above parameters as well as the reader distribution in those cases. It includes the evaluation of criticality indices in all the seven combinations and the possible reader locations. It also gives a measure of how the coverage would change according to the number of readers so that the system can be designed considering economic constraints as well.

General Case

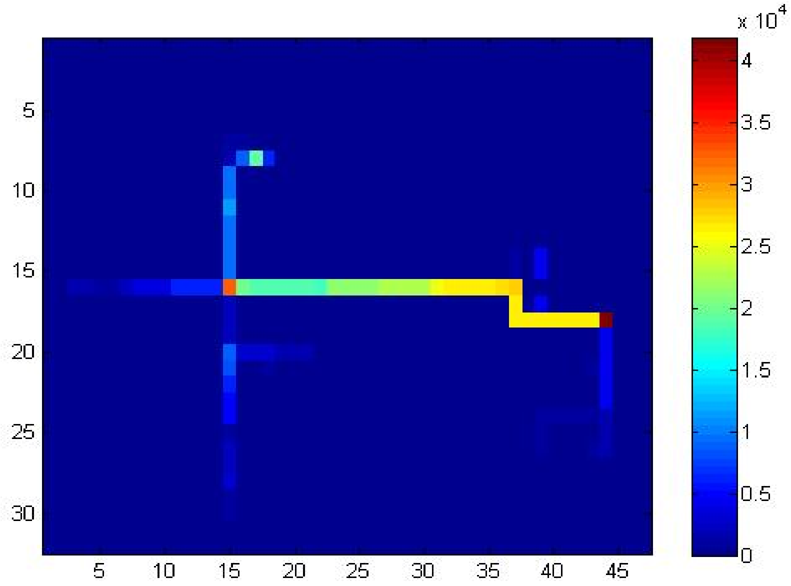


Fig. 4.6
Criticality index of the floor for general case

Definition of Criticality index:

$$c_i = \sum_{k=1}^{L} f_{ki} * (d_t)_{ki} * s_k$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% Coverage
Current	188	389	293	192	4.447%
Proposed	311	298	305	486	5.27%

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	6.62%	13.748%	21.913%	30.640%	41.644%

The criticality index field for general case is shown in Fig. 4.6.

Special cases:

1) CI based on Severity

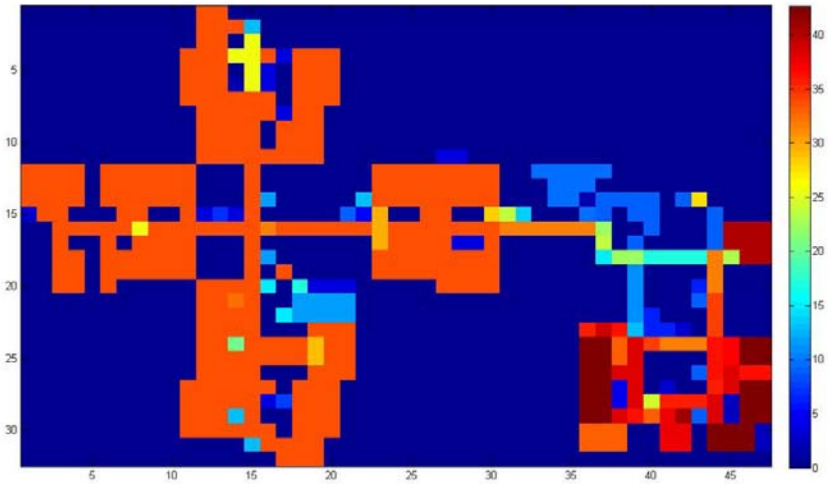


Fig. 4.7
Criticality index considering only severity as a parameter

Definition of CI:

$$C_i = \sum_{k=1}^{L} s_k$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% coverage
Current	188	389	293	192	0.5 %
Proposed	501	505	493	399	1.48%

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	1.85%	3.84%	5.09%	7.14%	8.61%

The current and proposed percentage coverage which can be achieved by evaluating criticality index on severity is very low as evaluated in the above table .

The coverage increases linearly on a small percentage scale by increasing the number of readers. This is justified by looking at the criticality index field and applying DCT's de-correlation property. The criticality index field as shown in Fig. 4.7 has lot of squares which are high valued and are correlated with each other. These squares appear in a cluster on all sides of the floor. As in the criticality index which considers only severity that is a static measure of the property of the criticality index, the high valued squares are closer to the storage places of the assets. Hence we can state from the criticality index field that there is no need of a sensor to track the assets; other types of identification devices can be used at storage places.

2) CI based on Frequency

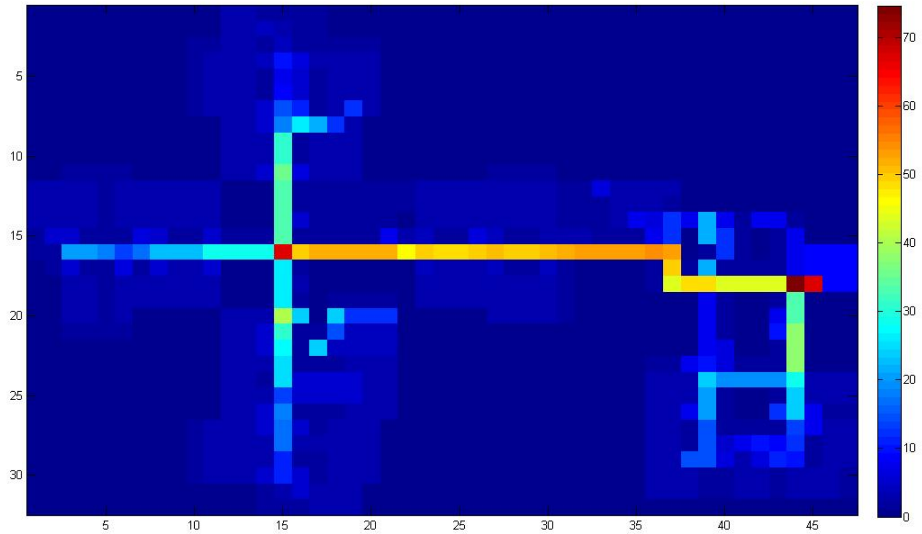


Fig. 4.8
Criticality index considering only frequency as a parameter

Definition of CI:

$$C_i = \sum_{k=1}^{L} f_{ki}$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% Coverage
Current	188	389	293	192	2.92 %
Proposed	486	385	421	157	4.63%

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	6.266 %	10.838%	15.176%	21.064%	25.175%

The evaluation of the criticality index in this case is based on frequency. The table above shows the amount of coverage with the present and proposed sensor system as well as the coverage achieved using flexible readers. The criticality index field as shown in Figure 4.8 shows high correlation among the squares on the corridor as the movement or frequency of movement is the main parameter under evaluation. In addition, the squares on the floor show high de-correlation and hence we can achieve more coverage in this case as compared with the criticality index evaluation using only severity. Such type of reader placement is ideal in cases where the assets are not stored and are constantly moving. Such type of reader placement will give more coverage in a very dynamic environment.

3) CI based on dwell time

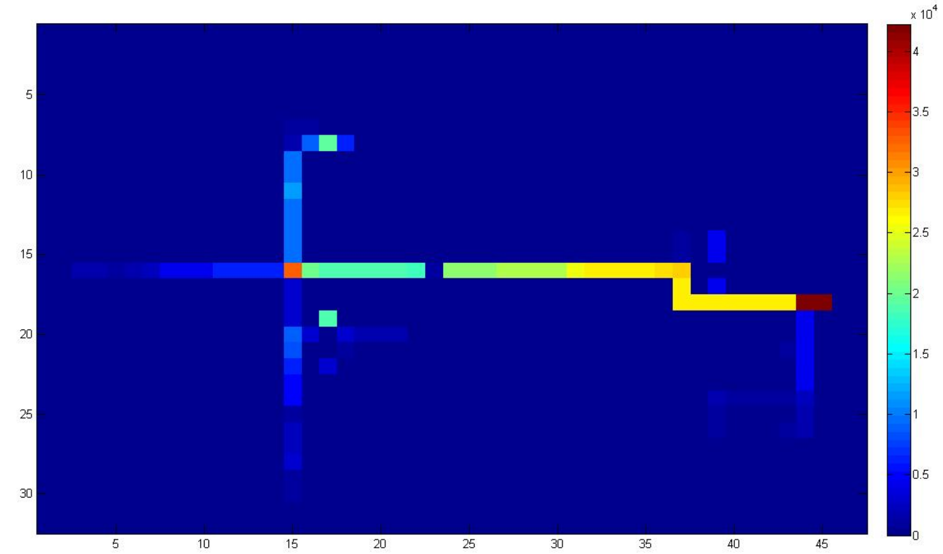


Fig. 4.9
Criticality index considering only dwell time as a parameter

Definition of CI:

$$C_i = \sum_{k=1}^{L} (d_t)_{ki}$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% Coverage
Current	188	389	293	192	5.51%
Proposed	486	463	438	422	7.55%

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	9.79%	20.04%	28.46%	38.55%	45.34%

Dwell time looks into any possibility of intermediate storage on the floor. In case where there is an intermediate storage, that particular square becomes a high valued square. Such type of reader placement can give maximum coverage as the asset is once stored at an intermediate place, it is under reader coverage until it is moved from there for further use. Looking at the criticality index field as shown in Fig. 4.9, it can be seen that the present system has intermediate storages and the coverage achieved is maximized among the individual parameters evaluated.

4) CI based on severity and frequency

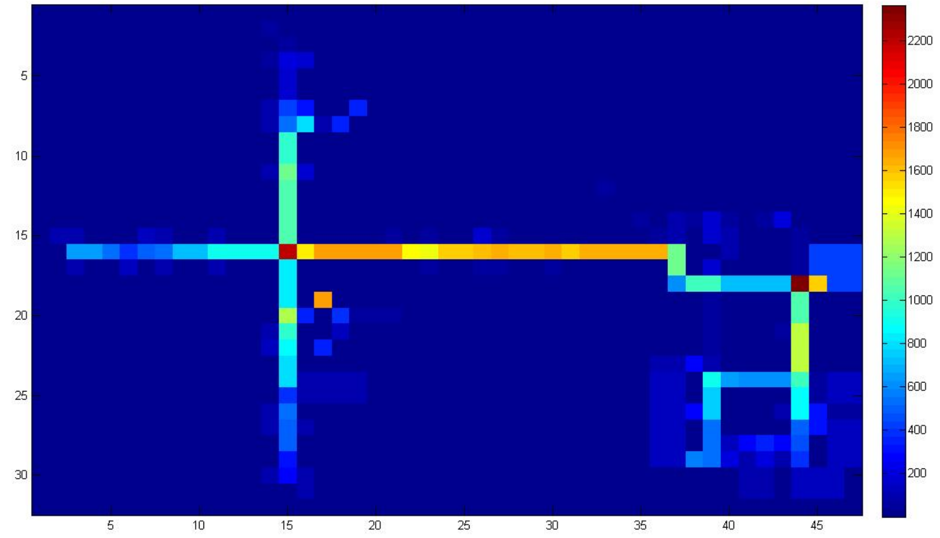


Fig. 4.10
Criticality index considering only severity and frequency as parameters

Definition of CI:

$$C_i = \sum_{k=1}^{L} s_k * f_{ki}$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% Coverage
Current	188	389	293	192	2.578%
Proposed	157	486	472	381	4.70%

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	5.879%	10.664%	15.382%	20.030%	24.555%

This case looks into reader placement based on the criticality index evaluated using both severity and frequency. The above table gives the percentage coverage and the proposed system coverage. The criticality index field in Fig. 4.10 shows that, this field is dominated by frequency. Comparing this field with the two individual fields demonstrates that the effect of severity is being appeased by the frequency.

5) CI based on severity and dwell time

Definition of CI:

$$C_i = \sum_{k=1}^{L} s_k *(d_t)_{ki}$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% Coverage
Current	188	389	293	192	3.500%
Proposed	486	381	157	472	9.150%

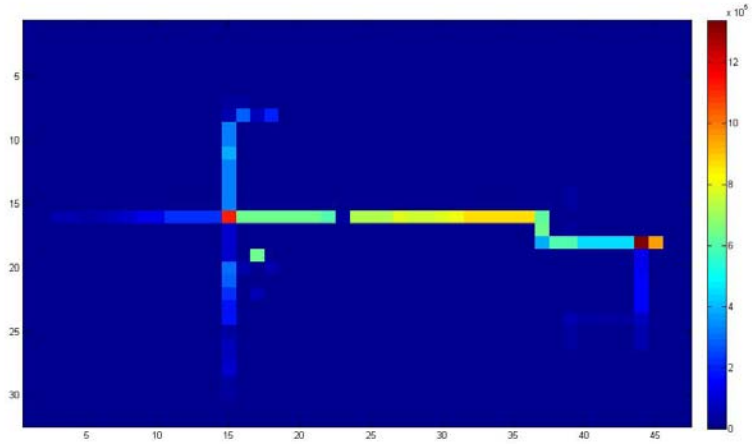


Fig. 4.11
Criticality index considering only severity and dwell time as parameters

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	11.022%	20.223%	28.683%	36.512%	43.415%

This case looks into the combination of severity and dwell time for evaluating the criticality index field as shown in Fig. 4.11. The table gives the measure of the coverage using the proposed system as well as flexible number of readers.

This case also allows a similar comparison as the previous case where the two parameters are compared with their combination. The coverage and the criticality index field show that this field is dominated by dwell time.

Reviewing the coverage achieved both the above cases show the effect of severity is appeased by frequency and dwell time.

6) CI based on frequency and dwell time

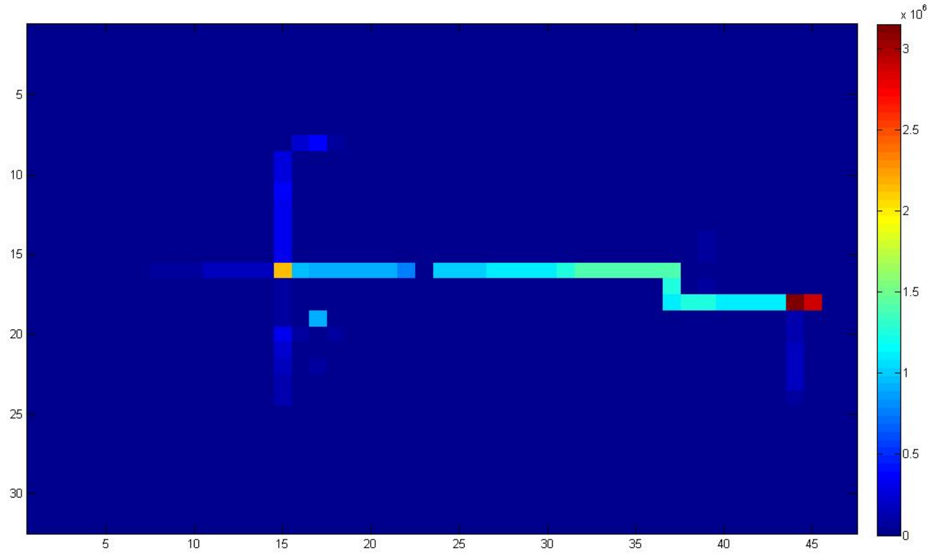


Fig. 4.12
Criticality index considering only severity as a parameter

Definition of CI:

$$C_i = \sum_{k=1}^{L} f_k * (d_t)_{ki}$$

Reader positions for 4 nodes

Readers Positions	Node 1	Node 2	Node 3	Node 4	% Coverage
Current	188	389	293	192	3.914%
Proposed	486	381	157	509	11.86%

% Coverage achieved with flexible coverage

Readers	5	10	15	20	25
% Coverage	15.603%	25.721%	34.970%	43.183%	50.970%

This case calculates the criticality index field based on the frequency and dwell time as shown in Fig. 4.12. Evaluation of the coverage achieved and the criticality index field concludes that this field shows highest de-correlation amongst the squares in some areas and it can be regarded as the probable reader positions. The coverage achieved in this case is maximized as compared to the previous cases.

Figure 4.13 shows the amount of coverage achieved in all the seven scenarios discussed.

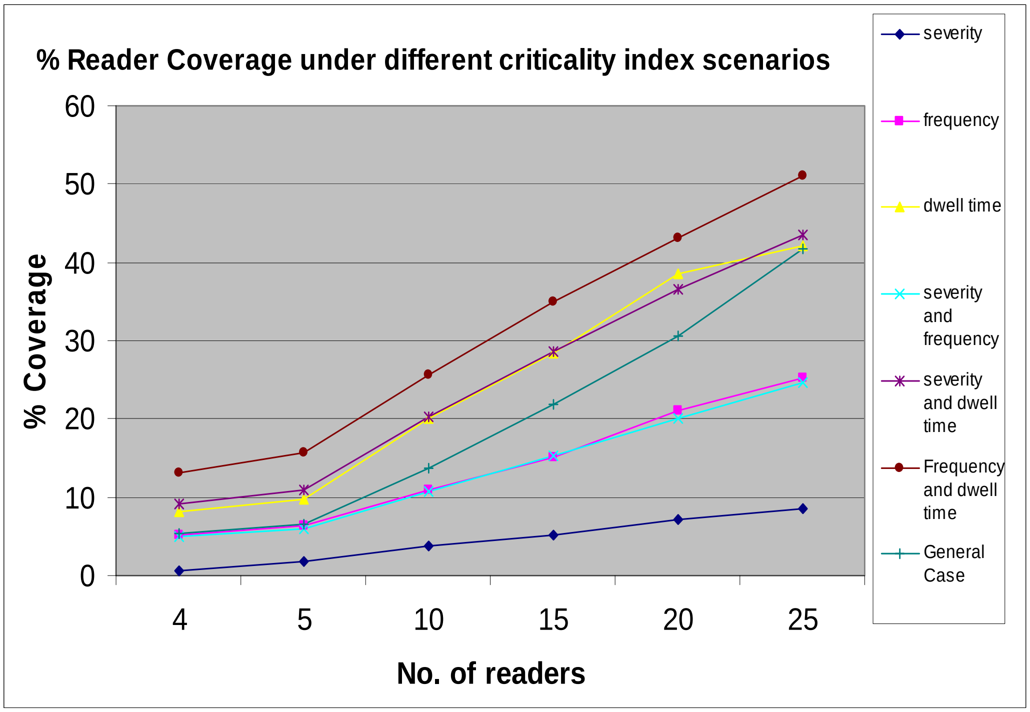


Fig 4.13
Graph showing % reader coverage under different criticality index cases

4.5 Evaluation of DCT properties for fast optimization and reader placement

The use of DCT properties as explained in the methodology can help in fast optimization and quick identification of reader positions. In this section a simulated case is used with a floor plan of 32×32 squares. As DCT operates on an 8×8 matrix, the floor is divided such that it has each section of size 8×8 squares. This section will execute the steps described in the chapter 3 to justify the use of DCT in the current reader placement problem under discussion.

Five assets are considered with the severity, frequency and dwell time parameters as shown in table below. Assume that the asset, once used, comes back to its storage location by following the same path.

Table 4.3 Asset information for DCT case

Asset Name	Severity	Frequency/day
Asset A	1	50
Asset B	2	4
Asset C	3	15
Asset D	4	20
Asset E	5	10

The storage locations are as shown in Fig. 4.14, below.

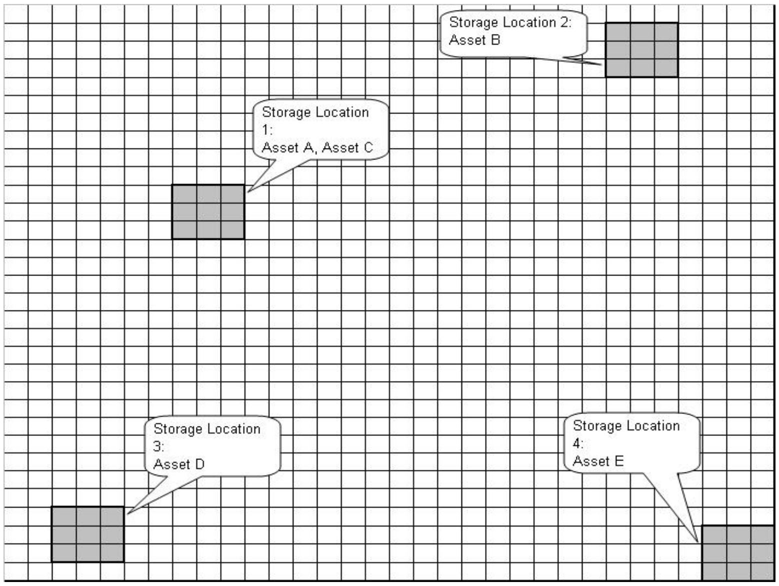


Fig. 4.14
Respective storage locations on the floor for assets

4.5.1 Mapping the flow patterns

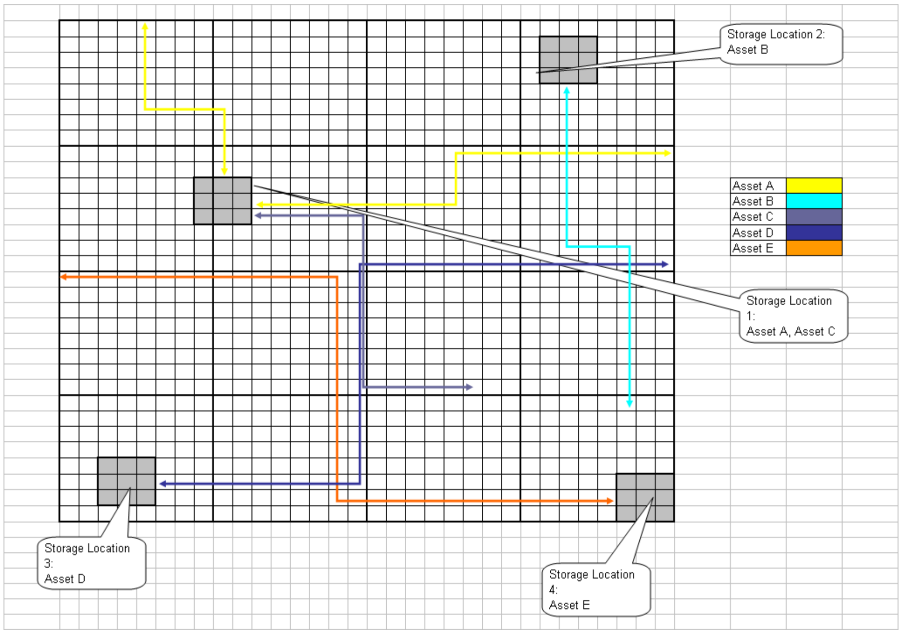


Fig. 4.15
Asset flows on the floor

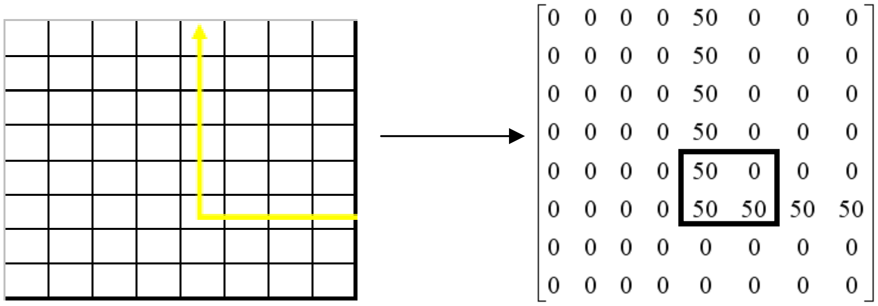
4.5.2 Dividing the floor plan into 8×8 matrices.

The floor plan is divided into multiple matrices of size 8×8 squares as shown in Fig. 4.15 and each matrix is evaluated one by one. There are 16 matrices which are to be evaluated using two properties of DCT, namely de-correlation and energy compaction. Reader allocation is determined on the basis of comparing the candidate portions which are important from reader allocation standpoint, using the following steps:

1. Evaluation and elimination of redundant and less important portions
2. Calculation of criticality index for important and more crowded portions.
3. Comparing the portions depending on the matrix values for reader positions

Matrix 1:

The section of a floor plan and its corresponding matrix is shown in Fig. 4.16. Only an asset “A” visits this part of the floor plan. The matrix shows there is high de-correlation between the adjoining squares.



$$\begin{bmatrix} 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 50 & 50 & 50 & 50 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Fig. 4.16
Matrix 1 calculation

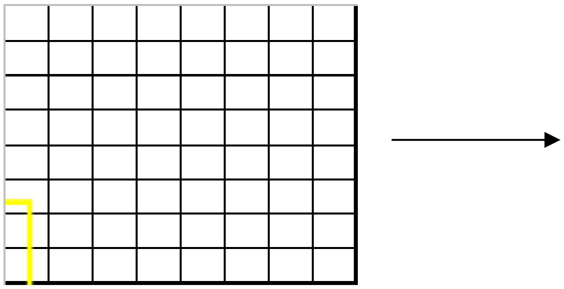
The criticality index of the redundant squares is zero as no asset travels through them. The criticality index of squares with asset “A” traveling through them is calculated using the same formula for the criticality index as follows.

$$C_i = \sum_{k=1}^{L} s_k * f_{ki} = 50 * 1 = 50$$

Here all the parameters carry the same meaning as explained while defining criticality index. The value of criticality indices is represented in the form of an 8×8 matrix.

The above representation is for the matrix A which is one part of the floor plan. The DCT properties which are applied in this case do not require actual calculating of the criticality index. But rather looking at the matrix we can analyze whether this matrix is important from the reader allocation stand point, using the de-correlation and energy compaction properties of DCT.

Matrix 2:



$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Fig. 4.17
Matrix 2 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.17. This portion shows that there is very little movement of assets on this part of the floor. A large number of the squares on this matrix are going to be redundant, with zero values. This matrix is not a probable candidate for the reader allocation.

Matrix 3:

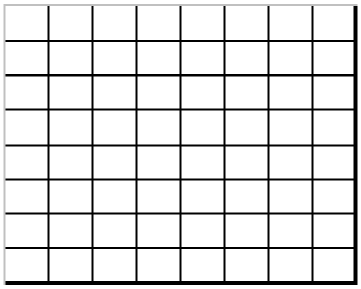
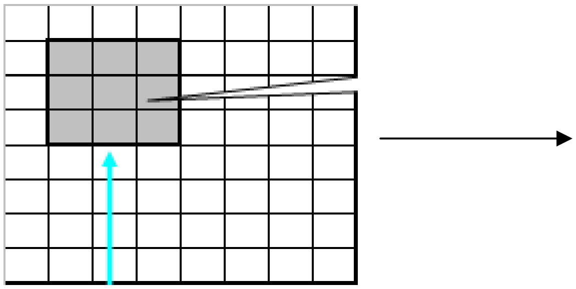


Fig. 4.18
Matrix 3 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.18. As there is no movement of the assets on this portion, we can treat this portion as the redundant one with the 8×8 matrix having all the values equal to zero.

Matrix 4:



$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 8 & 8 & 8 & 0 & 0 & 0 & 0 \\ 0 & 8 & 8 & 8 & 0 & 0 & 0 & 0 \\ 0 & 8 & 8 & 8 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Fig. 4.19
Matrix 4 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.19. This portion of the floor has a storage location as well as movement of assets. This portion might be a probable candidate for the reader allocation, which we will be evaluated by calculating the criticality index of the squares.

$$C_i = \sum_{k=1}^{L} s_k * f_{ki} = 2*4 = 8$$

Matrix 5:

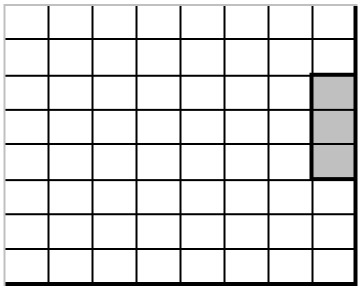
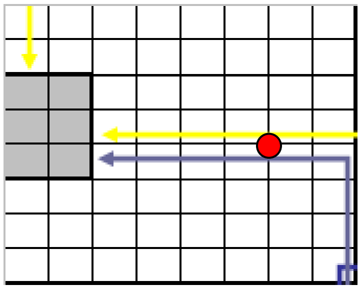


Fig. 4.20
Matrix 5 calculation

This portion of the floor has many redundant squares and a part of the storage location as shown in Fig. 4.20. We can ignore this portion and treat it as redundant.

Matrix 6:



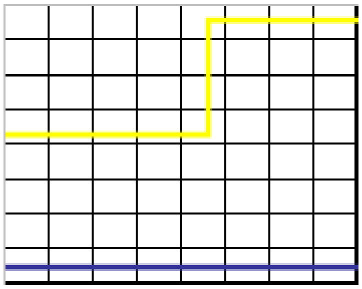
$$\longrightarrow \begin{bmatrix} 50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 50 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 95 & 95 & 0 & 0 & 0 & 0 & 0 & 0 \\ 95 & 95 & 50 & 50 & 50 & 50 & 50 & 50 \\ 95 & 95 & 45 & 45 & 45 & 45 & 45 & 45 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 45 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 45 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 135 \end{bmatrix}$$

Fig. 4.21
Matrix 6 calculation

This portion of the floor can be treated as more dynamic with a storage location and movement of multiple assets as shown in Fig. 4.21. This portion can certainly be treated as a candidate portion for reader allocation.

After evaluation of the matrix, probable reader position is shown on the floor plan.

Matrix 7:

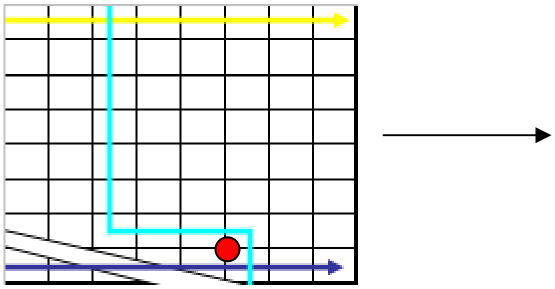


$$\longrightarrow \begin{bmatrix} 0 & 0 & 0 & 0 & 50 & 50 & 50 & 50 \\ 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 50 & 0 & 0 & 0 \\ 50 & 50 & 50 & 50 & 50 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 80 & 80 & 80 & 80 & 80 & 80 & 80 & 80 \end{bmatrix}$$

Fig. 4.22
Matrix 7 calculation

In this portion of the floor there are two assets flowing almost parallel to each other as shown in Fig. 4.22. A reader with a large read range would be needed to track both the assets.

Matrix 8:

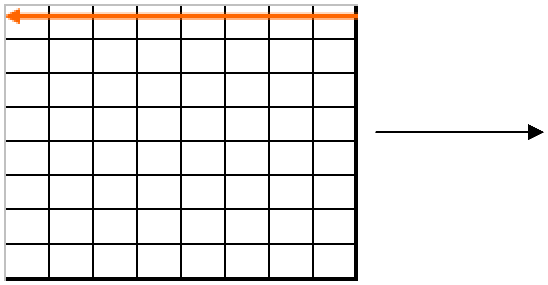


$$\begin{bmatrix} 50 & 50 & 58 & 50 & 50 & 50 & 50 & 50 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8 & 8 & 8 & 8 & 0 & 0 \\ 80 & 80 & 80 & 80 & 80 & 88 & 80 & 80 \end{bmatrix}$$

Fig. 4.23
Matrix 8 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.23. This portion of the floor plan has three assets moving through it. It can be a possible candidate for calculating the actual criticality indices of each square.

Matrix 9:

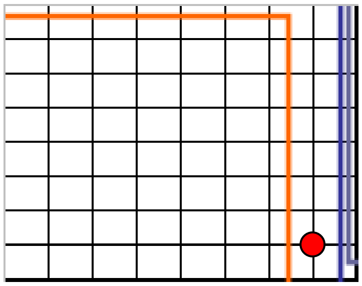


$$\begin{bmatrix} 50 & 50 & 50 & 50 & 50 & 50 & 50 & 50 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Fig. 4.24
Matrix 9 calculation

This portion has asset E moving on it in the top portion where but the other part of the floor is almost redundant as shown in Fig. 4.24. This might be considered a redundant portion.

Matrix 10:



$$\begin{bmatrix} 50 & 50 & 50 & 50 & 50 & 50 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \\ 0 & 0 & 0 & 0 & 0 & 0 & 50 & 125 \end{bmatrix}$$

Fig. 4.25
Matrix 10 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.25. This portion has assets C, D and E moving on it. These assets have relatively high severity as well as frequency; this can be regarded as an important portion for reader allocation. The criticality index of each square is calculated as shown in Fig. 4.25

Matrix 11:

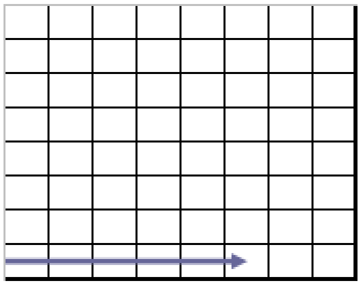


Fig. 4.26
Matrix 11 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.26. This portion is almost redundant; there is no need to calculate the criticality index of each square.

Matrix 12:

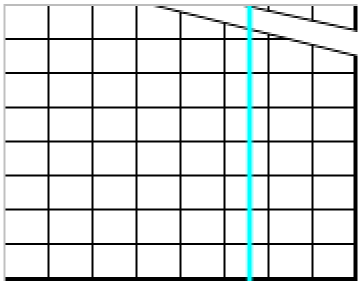
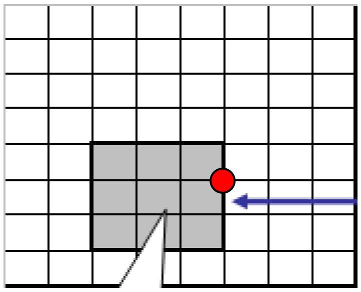


Fig. 4.27
Matrix 12 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.27. This portion of the floor is also almost redundant and not a probable candidate for the reader allocation.

Matrix 13:

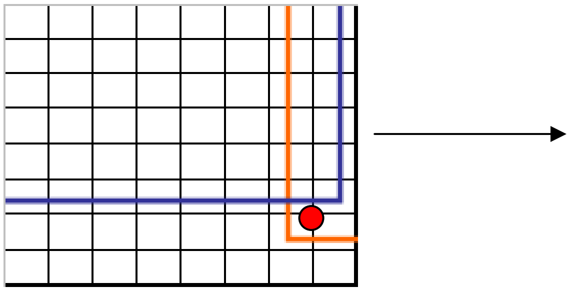


$$\xrightarrow{\qquad} \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 80 & 80 & 80 & 0 & 0 & 0 \\ 0 & 0 & 80 & 80 & 80 & 80 & 80 & 80 \\ 0 & 0 & 80 & 80 & 80 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Fig. 4.28
Matrix 13 calculation

The asset movement and the criticality index values for this portion are as shown in Fig. 4.28 and the criticality indices are represented in the matrix form.

Matrix 14:



$$\left[\begin{array}{cccccc|cc|}
0 & 0 & 0 & 0 & 0 & 0 & 50 & 80 \\
0 & 0 & 0 & 0 & 0 & 0 & 50 & 80 \\
0 & 0 & 0 & 0 & 0 & 0 & 50 & 80 \\
0 & 0 & 0 & 0 & 0 & 0 & 50 & 80 \\
0 & 0 & 0 & 0 & 0 & 0 & 50 & 80 \\ \cline{7-8}
80 & 80 & 80 & 80 & 80 & 80 & 130 & 80 \\
0 & 0 & 0 & 0 & 0 & 0 & 50 & 50 \\ \cline{7-8}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right]$$

Fig. 4.29
Matrix-14 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.29. This section can be treated as a dynamic one and the criticality index should be calculated for evaluating the reader position.

Matrix 15:

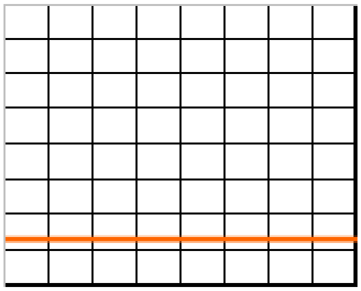
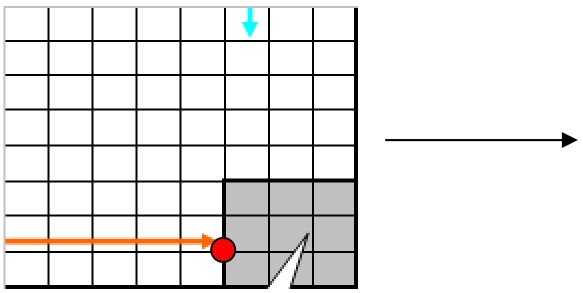


Fig. 4.30
Matrix 15 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.30. This portion is redundant and can be ignored.

Matrix 16:



$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 50 & 50 & 50 \\ 50 & 50 & 50 & 50 & 50 & 50 & 50 & 50 \\ 0 & 0 & 0 & 0 & 0 & 50 & 50 & 50 \end{bmatrix}$$

Fig. 4.31
Matrix 16 calculation

The section of a floor plan and its corresponding matrix is shown in Fig. 4.31. The criticality index for this portion of the floor is calculated for evaluating the reader position.

All the 16 matrices are evaluated separately for the de-correlation and energy compaction property of DCT. Seven of the 16 matrices should be further analyzed for evaluating the reader positions. Out of every probable candidate square matrix a 2×2 matrix is evaluated for the reader position, assuming the read range of the reader is limited to four squares. The 2×2 matrix consist of 4 equal sized squares. The values of the 2×2 matrix are added and tabulated as shown in Table 4.4. The higher the value of the matrix the more is weight of that particular portion of the floor, and more importance given to that area.

Table 4.4 Matrices with criticality index values

Matrix number	Criticality index value
1	150
6	190
8	184
10	350
13	240
14	310
16	150

The best reader positions for the four current readers can be found without evaluating the criticality indices of all the squares on the floor plan. This method gives a rapid and quick estimate of the reader positions. The best reader positions found are as shown on the floor plan below. Figure 4.32 shows the criticality index field calculated using DCT properties.

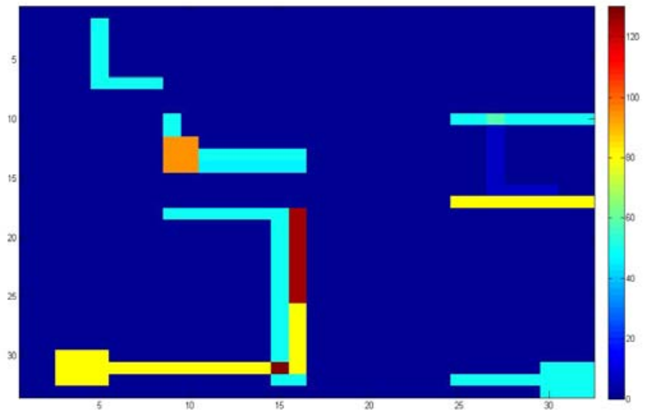


Fig. 4.32
Criticality index for the floor after applying the DCT properties

The goal in the design of such systems is to make it flexible according to the user requirements. Manual calculation of the criticality index poses limitations as it is a complex and time consuming process, where DCT properties help in evaluating the system according to the asset movements. With DCT criticality index of the square does not have to be calculated even if certain assets visit that square. De-correlation between adjacent squares defines the weight of the assets which travel on them. Evaluating the matrices for de-correlation identifies redundant squares which have very less traffic on them. Doing so actually saves much time involved in calculation of the criticality indices of those squares. After dividing the floor into equal sized squares represented as matrices of equal size, each portion of the floor is analyzed separately and tested for de-correlation property depending on two parameters

1. Type of asset visiting that particular portion
2. Presence of any storage location

Figure 4.33 can be used to compare the actual criticality index field after calculating the criticality index for all squares with the one using DCT properties.

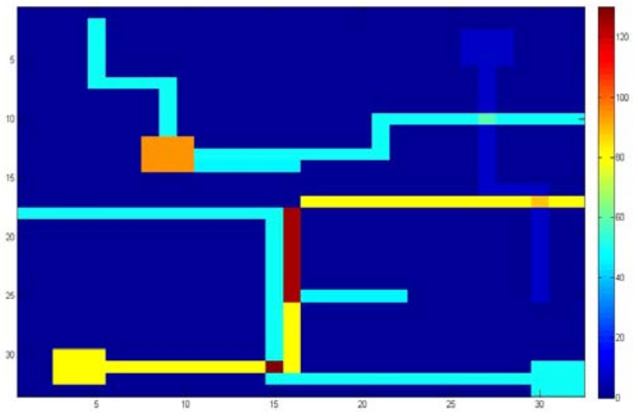


Fig. 4.33
Criticality index image obtained by manual calculation

After comparison of Fig. 4.32 and Fig. 4.33, it can be evaluated that lower values of the criticality index are associated with the remaining portion. The criticality index calculated manually have more correlated squares on the floor with low criticality index values. Our goal is to find de-correlated squares which have greater differences between their criticality indices and also have high criticality indices.

DCT properties help to find a set of efficient solutions which might become probable reader positions. Depending on that set further analysis will evaluate the best positions.

DCT properties can save significant amount of computation time associated with the calculation of criticality indices which are the important measure for evaluating the reader positions. While we evaluate the criticality index, we have divided the floor plan into size of 4×4 matrix, where each matrix is of size 8×8. In the case study to clearly state the property of discrete cosine transform, calculations were needed on only 7 out of 16 matrices, saving the computation time required for 9 matrices. More than 50% of the time required for the manual calculation of criticality index for each square was saved. DCT poses a powerful and efficient solution for computing a set of efficient solutions which are the probable candidates for reader positions. The best reader positions are as shown in Fig. 4.34.

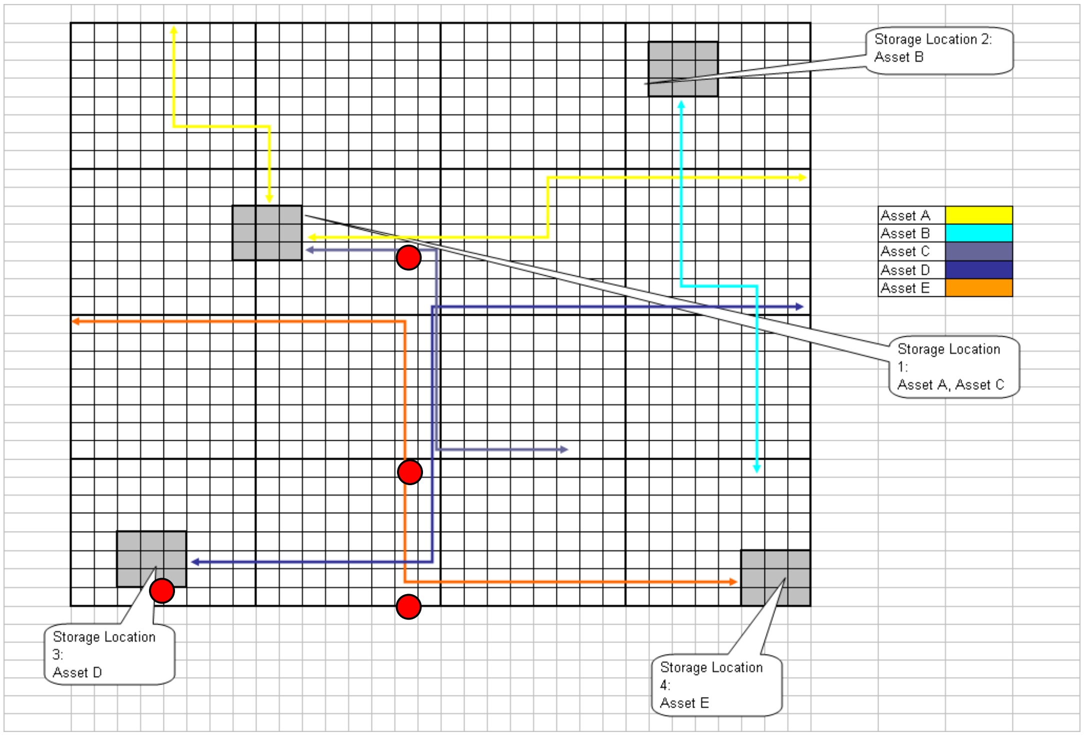


Fig. 4.34
Floor plan with the reader positions

CHAPTER V

CONCLUSION AND FUTURE WORK

The proposed research approach aims at healthcare, a very dynamic system where the asset management is extremely important. The proposed methodology is applied to an actual RFID system at Stillwater Medical Center. The research provides effective methodology to investigate various aspects of optimal RFID sensor placement. It provides guidelines for the parameters to be determined while designing RFID systems at healthcare facilities.

5.1 Optimizing the sensor placement with fixed number of readers

This scenario considers finding the best sensor positions with fixed number of readers in order to maximize the overall coverage of the system. In this case the maximal covering location allocation model is used for optimization of RFID sensor (reader) placement. The optimization model is formulated by considering the fixed number of readers due to the available budget. It can be found that there is significant improvement of RFID reader coverage achieved using the proposed method over the existing sensor placement.

The proposed method is based on the criticality index determined by important parameters related to assets, such as severity, frequency, and dwell time. Thus, the resulting RFID reader placement is more effective for asset tracking.

5.2 Reader allocation with flexible readers

This scenario considers flexible number of readers in order to achieve required coverage without any economic constraint. As shown in Fig. 4.13, the coverage achieved using different numbers of readers are evaluated in the case study. This result provides useful information for system designer to trade off between sensor system performance (RFID reader coverage) and economical consideration. RFID reader optimization can be further improved using discrete cosine transform. Here the main objective was to locate the squares with higher values of criticality indices which become the more probable candidates for reader coverage. Because the optimization model considers the collision factor in formulation of the objective function, the sensor positions are free from collision between multiple readers.

The system designed is user driven by which users can make decisions while deploying the system. The proposed method is based on the three parameters, namely severity, frequency, and dwell time. These parameters can be changed according the system requirements.

5.3 DCT and reader allocation:

The proposed methodology focusing on use of DCT to calculate the reader position has a great potential since the required criticality index calculations can be significantly reduced. This is more applicable in the frequently changing storage locations and traffic directions on the floor. The DCT methodology can be applied in case of complex and large sized floor plans which are difficult to analyze using ordinary calculation of criticality index. DCT also gives flexibility to adopt the system with varying ranges.

The proposed methodology with the satisfied RFID reader coverage provides some idea about the behavior of the overall system and the overall asset network. The colored zones in only severity based criticality index show high correlation between each other as shown in Fig. 5.2. Hence, multiple reader locations have common criticality index. This reduces the possibility of narrowing down the selection of the high valued squares which are too numerous in this case. DCT can be of great help in analyzing such grids to evaluate the probable sensor locations with minimum computations.

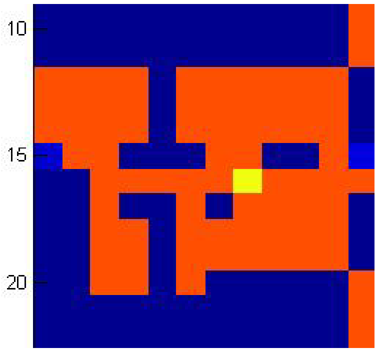


Fig. 5.2
Section of colored zone for criticality index calculation using severity only

In case of the flexible numbers of readers, the floor sections can be analyzed further for active floor sections. Depending on the frequency domains or the activeness of the floor sections, they can be evaluated for the probable reader positions. If the user wants to change the storage locations as well as the flow or path of the assets; it is easy to compute the criticality index using the DCT properties. Calculating only those floor sections which tend to show high de-correlation or high frequency domain by looking at the asset movements and referring to the type of the assets allows user to frequently change the system operation as per the requirements and still achieve the same performance. Advantages of DCT for sensor placement optimization include:

1. Significant reduction in computation time

2. Effectiveness for large sized grids
3. Applicable for dynamic systems with changing storage locations and asset flows

Thus, DCT proposes a powerful solution for evaluating a set of competent and efficient solutions with less computation time.

5.4 Future Scope

DCT can be effectively used for relatively more dynamic environments with multiple active frequency zones or floor portions. In such cases the square values are going to be fairly close to each other and it will be difficult to select the floor sections for the candidate positions of the readers. Thus, DCT can be applied to that particular section of the floor to evaluate the criticality index which can stand as a criterion for evaluation.

DCT can be applied to the case which has been evaluated at Stillwater Medical Center. Fig. 5.3 is a section taken from the Stillwater Medical Center 3rd floor plan. It is of size 8×8 matrix. The criticality index distribution in this case can be treated as a fairly complex and difficult to evaluate without any sophisticated approach such as the MCLP model in the case study.

The values in the top left corner in Figure 5.4 can be analyzed for comparing the two portions which have active critical index fields with more asset movement. This comparison is based on the values of the squares after DCT transformation in the top left corner of the DCT transformed matrix. If higher values are accumulated in the top left corner that matrix can be further analyzed for de-correlation and energy compaction properties which will result in a set of solutions depicting the reader positions.

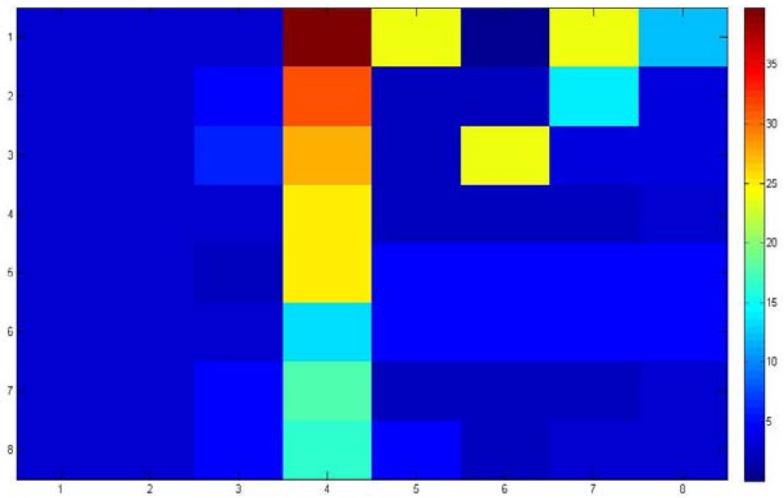


Fig. 5.3
Criticality index field for Stillwater Medical Center 3rd floor plan

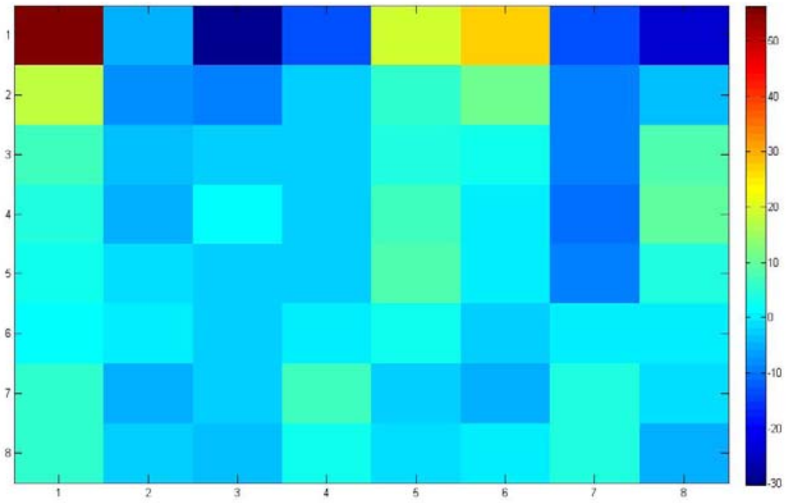


Fig. 5.4
Image after DCT transformation

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VITA

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Scope and Method of Study: The proposed research is focused on user driven real time asset tracking system design using radio frequency identification (RFID) technology in a dynamic healthcare environment. The research puts light on critical measures involved in information system of healthcare systems. The research develops an effective and efficient method for optimal RFID sensor placement based on the criticality index parameter for evaluation of sensor location importance. The Discrete Cosine Transformation (DCT) is applied to improve the computational efficiency. This proposed methodology is validated using both simulation data and an actual RFID system at Stillwater Medical Center, Stillwater, Oklahoma.

Findings and Conclusions: The research proposed new design methodology for RFID sensor (reader) placement. It improves the sensor coverage as well as the computational efficiency. The design of the system is user driven where user can change the parameters according to the requirements requested by the dynamic healthcare environment. The performance of the proposed methodology is compared with one of the existing system. The comparison results show that the sensor coverage can be improved from 15% to 66% for various definitions of the criticality index by using the proposed methodology. The utilization of DCT in sensor placement optimization can reduce the computational time by more than 50%. The proposed methodology is also capable of determining the number of sensors for the required coverage (or full coverage). This functionality provides the information for the tradeoff between sensor system performance and economical consideration.

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