Optimization of Using Devices Helping Patient Handling at Hospitals by Developing a Supply Chain Model

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ABSTRACT

Each year, thousands of nurses and other health care workers are injured from manually lifting patients. A few decades ago managers were mostly focusing on minimizing direct manufacturing costs but because of the competitive markets nowadays managers should also focus on indirect costs. In this situation the importance of supply chain networks and facility location problems becomes more visible. The need of sophisticated and applicable facility location models is vital and that’s because of indirect manufacturing costs (such as transportation, inventory, procurement & etc.) are considered in supply chain network and facility location models. Literature review is used to develop a model at hospitals in order to get a cost effective model for maximum availability of the products used in patient handling by minimizing the supply chain cost of automated patient handling. The products used for patient handling at hospitals are so expensive and they need to be arranged by a supply chain model to be used at maximum efficiency.
CHAPTER 1

INTRODUCTION

1.1 Introduction

Each year, thousands of nurses and other health care workers are injured from manually lifting patients. The injuries are the cumulative effect of years of lifting more than the human body can handle. The rate of back, shoulder, and neck injuries among health care workers exceeds that of workers in construction, mining and manufacturing. As a result, 50 percent of health care personnel suffer from chronic pain and at least 12 percent leave their jobs due to permanent and disabling injuries (Massachusetts Nurse Newsletter, 2009).

Hospitals or nursing homes should consider the adoption of new safe patient handling programs to improve clinical outcomes for patients; greater patient protection, safety and comfort; caregiver injury prevention; and improved caregiver performance and morale (Daynard et al., 2000).

One strategy is using improved patient-handling technique with existing equipment, and the other approach aimed at eliminating manual patient handling through the use of additional mechanical and other assistive equipment. Body
mechanics was part of the nurses’ training and education very early on in most nursing programs before going on into the clinical setting. This approach ensured that the newly acquired skill was practiced throughout all the nursing clinical rotations.

1.2 Problem Statement

a) What are the problems associated with non-manual handling of the patients?

b) What type of cost effective supply chain framework can be used at hospitals for decreasing the total cost of using devices and so increasing the availability of the products?

1.3 Project Objective

a) Develop questionnaire for nurses to evaluate the most prominent problem associated with patient handling at hospitals

b) Develop a supply chain model for minimizing the total costs regarding transfer assist devices used in handling of the patients at hospitals
1.4 Project Scope

a) Focus on nurses working in Malaysia (Their age is between 25-40, Their BMI (Body Mass Index) shows that they are not in the category of fat people, They are full-time workers (work for 5 shifts (8 hours shift) per week), Do not have previous back pain)

1.5 Report Summary

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Chapter 1 consists of introduction, problem background and project objectives. Chapter 2 consists of basic theory, history and definition including analysis and comparisons. Chapter 3 describes the project methodology. Chapter 4 describes data collection which provides the questionnaire for safe patient handling which will be mentioned in Chapter 5. At last, in Chapter 6 the conclusion and the future work will be described.
1.6 Summary

In this chapter a brief introduction to the project is described. The problem background and statement has been explained to give an overview of the project. The objective, scope and the importance of this project have also been described.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter covers the areas that are of interest to the study. Understanding on research area will let the researchers conduct and present the research study more easily. The main essentials such as definition, concept, policy, procedure, technology, best practices and the case study was analyzed and explained. All sources are obtained from literature review from books, journals, conference papers, research reports, theses, online search and standards. The aim is to broaden the understanding from the literature.
2.2 Definition of Facility Location and Supply Chain Management

Before starting the literature first the two main object of research area will be defined briefly which are Facility Location and Supply Chain Management (SCM). The general problem of facility location consists of several hospitals distributed in various areas and several facilities which should provide the hospitals products or services. There are also a set of parameters such as distance between hospitals and facilities, time or cost between them and the demand of each hospital (Drezner, Hamacher, 2004; Nickel, Puerto, 2005). The facility location model uses these parameters and finds the best solution (which is usually the solution with minimum cost) to answer the following questions (Melo et al., 2009):

1- Which facility should be open?
2- Which facility should provide which hospital(s) demand?

In addition there are some constraints such as facility capacity, demands, raw material that is considered.

Generally supply chain consists of all parties involved, directly or indirectly, in fulfilling a hospital request. Supply chain Management (SCM) includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers and even hospitals themselves (Chopra and Meindle, 2001). SCM is based on philosophy that the profit of all parties involved in a supply chain, are connected to each other. Thus, a single party such as manufacturer or supplier cannot increase its profit without cooperation from other parties. So the profit of all parties increases proportionally.

Because of enormous literature associated with supply chain and facility location, this literature only focus on papers of the last decade which are more up to date location allocation problems. In the following sections different types of facility location problems will be explained, general network of supply chain will be introduced.
2.2.1 Facility location Problems

Supply Chain Network Design (SCND):

Figure 2.1 shows the general network of supply chain. There are many aspects of the network which will be explained in this section.

In general suppliers support the manufacturing plants with raw material. As we can see from Figure 2.1 each supplier may provide materials for several plants and each plant may receive materials from several suppliers. Plants convert materials and other resources into products. These products are shipped to distribution centers. Distribution centers are usually sophisticated warehouses supporting the hospitals with products considering their demands. In fact the main purpose of distribution centers is to performing the coordination to make sure every hospital gets the right amount of products at right time.
In supply chain network as it can be seen from Figure 2.1 the flow of materials in the same layer is also possible. For example a distribution center can provide other distribution centers with products. These internal layer shipments help the supply chain network material balancing and inventory consolidation.

As it can be seen in supply chain network reverse flows are also considered. Generally in the last decade reverse logistics has attracted growing attention. Reverse activities are the activities which deal with collection and recovery of returned products in supply chain networks. Barros et al. (1998); Jayaraman et al. (1999) and Fleischmann et al. (1997) are the leaders in this area of research. They stated three points that justify the importance of this recent development:

1- Economics: through return of products it is possible to recapture the materials of used products.
2- Governmental directives: some standards force companies to collect their environmental harmful products. (for example the European Union WEEE)
3- Customer expectation: consumers of product expect the company to collect and replace the defected products.

In supply chain networks there are usually some specific facilities to support the reverse logistics activities. These facilities are usually categorized into two types, collection centers and recovery plants. Collection centers are the facilities where hospitals return the used or defective products. But recovery plants are the facilities in which repairing and remanufacturing activities are done. However these activities in some cases take place in warehouses or manufacturing plants.
Basic features of Supply Chain Network:

There are four important features of SCN that most of the researchers try to deal with in their model. But in surveyed literature no model could include all these features and there are only a few models which included three of these features (Refer to Table 2.1). These features are explained in the following:

a) Multi commodities

As mentioned earlier in many facility location models researchers consider only one product in the model but it is not the case for most of the real supply networks. Nowadays it is hard to find plants that produce only one product so the single-product assumption decreases the applicability of model noticeably. So it is vital to develop models which cover multiple products.

b) Multiple location layers

Another important issue is the number of layers which are included in the model. As we can see in Figure 2.1 there are several layers associated with supply chain network. A good model should include all these layers. But in the surveyed literature there were only a few models which really considered all associated layers.

c) Multi-periods models

A supply chain network should be designed in a way that can be used for a long period of time due to the large investment in this phase. So if a single period
model is chosen it is more desirable to have high level of stability. If there is not enough stability it is essential to develop a model robust enough to accommodate future changes. To allow future changes in network structure, time horizon should be divided into several time periods. These types of models are called multi-period models. In multi-period models strategic decision are to be made independently for each period so the issue of instability would be resolved. Also to resolve the problem of high investment in strategic decisions each period is limited by a specific budget. So facilities that have less investment (such as warehouses) may experience more fundamental changes and facilities with high investment (manufacturing plants) usually experience smaller changes over the period.

From discussions in this section it can be concluded that there are four basic features: multiple commodities, multi-layer, single period or multi-periods, and deterministic/stochastic. M.T. Melo et al. (2009) categorized all recent facility location papers based on these four aspects as shown in Table 2.1.

It should be noted that considering multi-layer aspect does not mean that the model must also consider location selection option for all layers. So it is possible that a model that considers the multi-layers is actually only location decision option for one layer. Therefore Table 2.1 classifies papers based on both number of considered layers and number of layers in which location decisions are allowed. Models in which multiple layers are considered but location decision is allowed for only one layer, that layer usually would be intermediate layer which is distribution centers or warehouses.
Table 2.1: Supply chain structure featuring the number of commodities, the nature of the planning horizon (single-/multi-period) and the type of data (deterministic/stochastic). (Adopted from: Melo et al., 2009)

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- P. Kouvelis et al. (2002)

**Stochastic**
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2.3 Problem Background

From a study in the USA the following statistics shows the pain due to patient handling:

a) 52 percent of nurses and caregivers complain of chronic back pain
b) 12 percent of nurses are contemplating "leaving for good" because of back pain
c) 20 percent of nurses have transferred to a different unit, position or employment opportunity because of lower back pain
d) 38 percent have suffered occupational-related back pain severe enough to require leave from work
e) 6 percent, 8 percent and 11 percent of RNs reported changing jobs for neck, shoulder and back problems, respectively (Massachusetts Nurse Newsletter, 2009).

The rate of back injuries among nurses and other health care workers who handle patients is serious. The data of the Bureau of Labor Statistics (USA) in 1996 showed that the incidence of non-fatal (reported) injuries in health care services was 8.5 per 100 full-time workers. This rate is not significantly different than that of manufacturing and construction.

Acute back-related disorders occur in highest frequency during patient lifts, transfers and boosts. There are significant personal risk factors that are well known to pre-dispose to back injury vulnerability such as aging, obesity, smoking and previous back injury. Additionally, psychosocial issues such as job dissatisfaction, depression and various life stresses may pre-dispose nurses to a life altering back injury. Health and quality of life are greatly reduced for a large proportion of the population due to acute and chronic musculoskeletal disorders.
Common prevention strategies include non-manual patient handling. Much mechanical equipment has been developed as the nurses’ assistants for patient handling. It is also important to assess the forces acting on human bodies and biomechanical analysis. Results from epidemiological studies showed strong evidence for an association between manual material handling, frequent bending and twisting, physically heavy work, whole body vibration (Bernard, 1997; Hoogendoorn et al., 1999). Several of these risk factors are present in patient-handling tasks. Biomechanical studies have estimated the load on the low back in several patient-handling tasks (Daynard et al., 2001; de Looze et al., 1994; Dehlin and Lindberg, 1975; Gagnon et al., 1986, 1987, 1988; Garg et al., 1991a, b; Garg and Owen, 1993; Lindbeck and Engkvist, 1993; Ulin et al., 1997; Winkelmolen et al., 1994).

Patient handling can be categorized into categories as described by Schibye et al., (2003).

### Recommended techniques during the various patient-handling tasks

1. **Turn patient in bed towards the HCW from his back to his left side (causing his face to turn towards HCW).**
   - Patient: Right knee flexed, right arm crossed over the trunk, head turned to the left. HCW: Stands in a walking position perpendicular to the bed with her left foot in front, her left hand on the knee and her right hand on the patient's right shoulder. Patient is instructed to make a set off with his right leg. At the same time, HCW shifts her weight from her front leg to her rear leg thereby pulling him over.

2. **Reposition patient from lying on the back in the middle of the bed to the nearest bedside.**
   - Patient: Both legs flexed and foam rubber washcloth under his feet. HCW: Stands in a walking position perpendicular to the bed with her right foot in front, her right hand under the patient's pelvis and her left hand on his knees. Patient is told to lift his pelvis and at the same time HCW pulls it to the edge of the bed by making a weight transfer. To reposition the shoulders, the pillow is placed under the scapula and used for pulling this part to the bedside.}
3. Turn patient in bed away from HCW from his back to his right side. Patient: Left leg flexed, left arm crossed over his trunk, head turned to the right. HCW: Stands in a walking position perpendicular to the bed with her right foot in front, left hand on the knee and her right hand on the patient’s left shoulder. Patient told to make a set off with his left leg. At the same time HCW shifts weight from her rear leg to her front leg thereby pushing him over on his side. To reposition him, the pelvis is further tilted by pulling with her right hand under the lower part of the pelvis and pushing with her left hand on upper part of the pelvis. The shoulders are repositioned by pulling with her right hand under the right shoulder and pushing with her left hand on his left shoulder. 3x. The same procedure as in task 3 except the HCW uses a plastic bag around her right hand when repositioning the pelvis and shoulders.

4. Elevate patient from supine position to sitting on edge of the bed. Patient: Turned to his left side (As task 1) but with both legs flexed. Instructed to move his legs over the edge of the bed. HCW: Stands in a walking position beside the bed with her feet in an angle of 45° to the bed. Left hand on his upper hip and her right arm under his neck and thorax. Patient instructed to set off with his right arm and left elbow. At the same time, HCW shifts weight from her rear leg to her front leg thereby pushing him into sitting position.

5. Move patient from sitting on the edge of the bed to standing on the floor. Patient: Feet placed just below knee. Instructed to lean forward and put the right hand around the shoulder of HCW. HCW: Stands in a walking position in front of patient with her right foot in front and her feet perpendicular to the bed. Patient is asked to rise and with her right hand at his left scapula and his left hand on his right upper arm, the HCW is at the same time pulling him forward by shifting her weight from her front to her rear foot, where after he rises slowly.

6. Move patient from sitting on the bed to supine position. Patient: The head part of the bed is elevated to 45° position. HCW: Stands in front of patient with the patient’s right hand on her right hand. Patient is now instructed to be down on his left side and turn to his back. In this procedure HCW is guiding and decelerating the movements. Now HCW places herself in a walking position beside the bed with her feet in an angle of 45° to the bed side with her left foot in front and with her head facing the foot of the bed. Patient is instructed to lift his legs and HCW at the same time helps by lifting the legs while she is making a weight transfer forward from her right to her left leg (HCW has both hands below the patient’s lower legs).

7. Reposition patient posteriorly in the seat of the wheelchair. Patient: Feet placed just below his knees. Instructed to lean forward and put his right hand around the shoulder of HCW. HCW: Stands in a walking position in front of the patient with her left foot in front and with both hands on the patient’s shoulders. HCW is now pulling him forward by transferring her weight backwards. As a result, the patient’s weight is shifted to his feet and his bottom is elevated. He is told to push backwards with his feet while the HCW is gently pushing him.

8. Reposition the supine patient towards the head of the bed, HCW at the head of the bed. Patient: Both knees flexed and foam rubber washcloth under the feet. HCW: Stands in a walking position at the head of the bed; a plastic bag is placed under the pillow below the shoulders. Patient is instructed to lift his pelvis and push himself upwards with the legs. At the same time HCW pulls the pillow (and him) upwards by making a weight transfer backwards.

8x. Reposition the supine patient towards the head of the bed, HCW at the foot of the bed. Patient: A plastic bag is placed under the pillow on shoulder level. Instructed to flex both knees and a foam rubber washcloth is placed under his feet. HCW: Stands at the foot of the bed and instructs the patient to lift his pelvis, push with his legs and pull in the bedhead with his right arm.

Figure 2.2 Different types of patient handling (Journal of Biomechanics 35 (2002) 1357–1366 (Skotte et al., 2002)).
2.3.1 Effectiveness of Two Patient Handling Approaches

Daynard (et al., 2000) studied two strategies in patient handling. One strategy involved using improved patient-handling technique with existing equipment, and the other approach aimed at eliminating manual patient handling through the use of additional mechanical and other assistive equipment. Personnel in both groups received training in back care, patient assessment, and use of the equipment available on their particular wards. An analysis of compliance with interventions and the effects of patient-handling methods on both peak and cumulative spinal compression and shear during various tasks were conducted. Within this study, cumulative spinal loads refer to the amount of compressive or shear force that is placed on the spine during the course of a single-patient-handling activity. Durations of single activities are typically several seconds to more than a minute of manual handling and adjustment of patient positions. The study used a quasi-dynamic biomechanical computer model of the lumbar spine to assess both peak and cumulative compressive and shear loads at L4/L5 during a series of patient-handling activities.

Many studies found that lifting and transferring patients was the primary cause of injury in nursing personnel (Yassi et al., 1995) as well as the major source of residual disability (Cooper et al., 1998).

Consequently, a three-group, randomized control trial was implemented within the hospital with the aim of decreasing the incidence and severity of patient lift and transfer injuries. The first group (A) represented the control group; receiving no formal education or training. Group B received general back-care education and specific technique training for equipment already available in the wards. The third group (C) received similar education as B, but wards within this group were also provided with new mechanical lift and transfer equipment and were trained in its use. The objective of the biomechanical study was to assess and compare the effectiveness of these injury prevention strategies in reducing injury risk, as
estimated from compliance with interventions and reductions in selected risk factors, namely peak and cumulative spinal compression and reaction shear, during simulations of patient-handling tasks.

Both education/technique training and new assistive handling equipment reduced spinal loading in several tasks. In bed-to-wheelchair transfer and chair boosts of patients, lack of training or non-compliance resulted in spinal loading that was risky according to suggested limits for spinal compression and/or spinal shear forces, while compliance with interventions brought loads within acceptable values. However, examination of cumulative spinal loads reveals that, in many cases, the use of assistive equipment increases exposure to problematic prolonged, albeit low level, spinal loads, as more actions are required to complete the transfers (Daynard et al., 2000).

2.3.2 Task with Lowest Risk of Injury

Muriti (et al., 2005) observed staff performing manual patient handling tasks. In the absence of patient lifting hoists are at an elevated risk of musculoskeletal injuries. The research tries to identify patient handling methods that have the lowest risk of injury. The patient handling task of lifting a patient from floor to a chair or wheelchair is a common task performed.

The task was performed utilizing three methods, these being: (1) heads/tails lift, (2) use of two slings and (3) use of a draw sheet. The task of the heads/tails lift was broken down into two distinctly separate subtasks: lifting from the (1) head and (2) tail ends of the patient load. These techniques were selected based on criteria including current practice, durability, portability, accessibility, ease of storage and cost to supply. Postural data were obtained using a three-dimensional motion measurement and analysis system in the Biomechanics & Gait laboratory at the University of New South Wales. Forty reflective markers were placed on the subject
to obtain the following joint angles: ankle, knee, hip, torso, shoulder, elbow, and wrist. The raw data were converted into the respective joint angles (Y, X, Z) for further analysis.

The postural data was analyzed using the University of Michigan’s Three-Dimensional Static Strength Prediction Program (3D SSPP) and the relative risk of injury was based on the following three values: (1) a threshold value of 3,400 N for compression force, (2) a threshold value of 500 N for shear force, and (3) population strength capability data. The effects on changes to the anthropometric data was estimated and analyzed using the in-built anthropometric data contained within the 3D SSPP program for 6 separate lifter scenarios, these being male and female 5th, 50th and 95th percentiles. Changes to the patient load were estimated and analyzed using the same computer software. Estimated compressive and shear forces were found to be lower with the draw sheet and tail component of the heads/tails lift in comparison to the use of the straps and head component of the heads/tails lift. The results obtained for the strength capability aspect of each of the lifts indicated a higher percentage of the population capable of both the draw sheet and tail end of the heads/tails lift.

The relative risk of back injury for the lifters is distributed more evenly with the draw sheet lift as opposed to the heads/tails (tail) lift where risk is disproportionate with the heavier end being lifted. The use of lifter anthropometrics does not appear to be a realistic variable to base assumptions on which group of the population are capable of safely performing this task in a remote setting. This study advocates the use of the draw sheet lift. The draw sheet lift is both more accessible and provides a more acceptable risk when more than two patient handlers are involved, in comparison to the other lifts utilized lifting patients from floor to a chair (Muriti et al., 2005).
2.3.3 Specific Patient Handling Tasks

NCBI, U.S. National Library of Medicine and National Institute of Health study used both a comprehensive evaluation system (low-back disorder risk model) and theoretical model (biomechanical spinal loading model) to evaluate risk of LBD of 17 participants (12 experienced and five inexperienced) performing several patient handling tasks. Eight of the participants were female and nine were male. Several patient transfers were evaluated as well as repositioning of the patient in bed; these were performed with one and two people. The patient transfers were between bed and wheelchair (fixed and removable arms) and between commode chair and hospital chair. A 'standard' patient (a 50 kg co-operative female; non-weight bearing but had use of upper body) was used in all patient handling tasks. Overall, patient handling was found to be an extremely hazardous job that had substantial risk of causing a low-back injury whether with one or two patient handlers.

The greatest risk was associated with the one-person transferring techniques with the actual task being performed having a limited effect. The repositioning techniques were found to have significant risk of LBD associated with them with the single hook method having the highest LBD risk and spinal loads that exceeded the tolerance limits (worst patient handling job). The two-person draw sheet repositioning technique had relatively high spinal loads and LBD risk. Thus, even the safest of tasks (of the tasks evaluated in this study) had significant risk. The study represented a 'best' case scenario since the patient was relatively light and co-operative. Patient handling in real situations such as in a nursing home would be expected to be worse. Therefore, to have an impact on LBD, it is necessary to provide mechanical lift assist devices (NCBI, 1999).
2.3.4 Risk Injury while Carrying Patient from One Chair to Another Chair

According to Elford et al., (1997), health professionals handling patients are to be at risk of sustaining work related low back injuries. This study used kinematic variables and subjective ratings of body part stress and lifter preference as measures of relative risk for three two-person techniques for carrying a patient from one chair to another chair. The techniques used no slings, one and two slings respectively. Twenty-two nurses performed five trials each of the three techniques. Kinematic measures of angular displacement, velocity and acceleration were obtained using the lumbar motion monitor and visual analogue scales were used to obtain measures of body part stress for seven body parts. Angular displacement, velocity and acceleration were significantly greater in the frontal, sagittal and transverse planes for the no sling technique compared to techniques using slings.

Comparatively small yet significant differences between techniques using slings were recorded for sagittal flexion and rotation. There was no significant difference between one and two sling techniques for other dependent variables. Mean total body stress rating was higher for the no sling technique and all subjects indicated that their first preference was for slings. Although all three measures of risk rated the no sling technique as carrying a higher level of risk than the techniques using slings. No single measure adequately captured all aspects of relative risk. The elimination of manual patient handling is thought to be the best option for the reduction of work related back injuries in patient handlers. Where resources or technology are not yet adequate to provide practical alternatives and where the use of manual technique for a seat to seat task is unavoidable, the use of patient handling slings will reduce the risk (Elford et al., 1997).
2.3.5 Validating NIOSH Method for the Design and Evaluation of Manual Lifting Tasks

In 1981, the National Institute for Occupational Safety and Health (NIOSH) published a comprehensive guide for the evaluation and design of manual lifting, based on epidemiological, physiological, psychophysical, and biomechanical knowledge. A revised version of the easy-to-use NIOSH lifting equation was provided in 1991 considering occasional new findings from literature. For assessing the load on the lumbar spine during lifting, a limit of 3.4 KN for lumbosacral disc compression was introduced.

Figure 2.3 NIOSH USA values for the compressive strength of lumbar-spine elements in accordance with age in years.
Epidemiological studies showing the relationships between low-back disorder incidence rates and lumbar mechanical exposures cannot be used for confirming the 3.4 KN value as an appropriate limit. It is concluded that the 3.4 KN criterions is substantiated neither epidemiologically nor biomechanically by the provided sources.

The criterion 350 kg/3.4 KN compressions on the lumbosacral disc is supported neither biomechanically nor epidemiologically. In a future approach, age and gender should be considered in a revised NIOSH lifting equation (Matthias et al., 1997).

2.3.6 Prevention of Back Injuries

Occupational back pain in nurses (OBPN) constitutes a major source of morbidity in the health care environment. According to the National Institute for Occupational Safety and Health (NIOSH), occupational back injury is the second leading occupational injury in the United States. Among health care personnel, nurses have the highest rate of back pain, with an annual prevalence of 40-50% and a lifetime prevalence of 35-80%. The American Nursing Association believes that manual patient handling is unsafe and is directly responsible for musculoskeletal disorders encountered in nurses. It has been well documented that patient handling can be done safely with the use of assistive equipment and devices that eliminate these hazards to nurses that invite serious back injuries.

The benefit of assistive patient handling equipment is characterized by the simultaneous reduction of the risk of musculoskeletal injury to the nursing staff and improvement in the quality of care for patient populations. To understand the cause of disabling injuries in health care workers, several factors must be considered, including the following: (1) anatomy/physiology of the back, (2) risk factors, (3)
medical legal implications, and (4) prevention. Among nurses, back, neck, and shoulder injuries are commonly noted as the most prevalent and debilitating. While mostly associated with dependant patient care, the risk for musculoskeletal injury secondary to manual patient handling crosses all specialty areas of nursing. The skeletal defects of an abnormal back make the back more susceptible to occupational injury, even under normal stress conditions.

Experts believe that training in proper body mechanics does not prevent back injury. Consequently, focus has been placed on other innovative injury prevention programs, including the use of engineering controls as well as the “lift team” method. Ergonomics involves the use of mechanical devices (e.g., walking belt and mechanical hoist) to aid in patient lifting and transferring tasks. Ceiling lift systems and slings can cater to challenging conditions and complex environments.

Ceiling-mounted hoist system consists of a wide range of lifting units, rail components, and a complete assortment of lifting slings and accessories. Sling can be made of polyester, which is characterized by its strength and elasticity. The "lift team" method was devised to remove nursing personnel from the everyday task of moving patients. This type of intervention assumes that lifting is a specialized skill to be performed only by expert professional patient movers who have been thoroughly trained in the latest lifting device techniques (Edlichet et al., 2004).

2.3.7 Relevance of Low Back Pain and Lifting

The incidence of low back pain has continued to increase in modern society, despite the considerable amount of scientific research that has aimed to isolate its exact etiology. Although low back pain is still largely idiopathic, research has
identified over one hundred risk factors for the condition. Of these risk factors, manual material handling tasks are perhaps the most widely explored within the biomechanical literature, as these tasks have been associated with high mechanical stresses on the lower back. Numerous technique-related variables have been addressed by researchers, whilst the influence of intra-abdominal pressure has also been considered. In addition to this, the implications of variations in the size and structural composition of the load have also been assessed.

2.4 Comparison

There are many aspects of patient handling techniques which can reduce the injuries. This study focus on pains associated with patient lifting and limited to design risk assessment methods for patient handling both the nurses and the patients.

As a summary of the literature review a table of the researches is brought in this section like as below:

**Table 2.2 Table of previous researches**

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Year</th>
<th>Field of Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skott</td>
<td>2002</td>
<td>Net moment and shear force at L4/L5 joint</td>
</tr>
<tr>
<td>Daynard</td>
<td>2000</td>
<td>Effectiveness of two patient handling approaches</td>
</tr>
<tr>
<td>Murtiri</td>
<td>2005</td>
<td>Task with lower risk of injuries</td>
</tr>
<tr>
<td>NCBI</td>
<td>2002</td>
<td>L5/S1 loading, posture of segments, inertial parameters, EMG</td>
</tr>
<tr>
<td>NCBI</td>
<td>1999</td>
<td>Specific patient handling tasks</td>
</tr>
<tr>
<td>Schibye</td>
<td>2003</td>
<td>Assessing the changes in the mechanical load</td>
</tr>
<tr>
<td>Author</td>
<td>Year</td>
<td>Title</td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Wendy Elford</td>
<td>1997</td>
<td>Risk injury while carrying patient from one chair to another chair</td>
</tr>
<tr>
<td>NIOSH</td>
<td>1981</td>
<td>Validating NIOSH method for the design and evaluation of manual lifting tasks</td>
</tr>
<tr>
<td>Christopher S. Pan</td>
<td>1997</td>
<td>Biomechanical stresses</td>
</tr>
<tr>
<td>Christian Larivi &amp;</td>
<td>1999</td>
<td>3D-Biomechanical analysis of simple and complex lifting tasks</td>
</tr>
<tr>
<td>Gragnon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBPN</td>
<td>2004</td>
<td>Prevention of back injuries</td>
</tr>
<tr>
<td>Ramos Vieira</td>
<td>2008</td>
<td>Physical demands of frequent nursing tasks</td>
</tr>
</tbody>
</table>
CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

An appropriate methodology, models and techniques must be determined prior to the execution of the project. To develop the model for analysis of the problems during patient handling, quantitative and qualitative approach have been chosen.

This chapter describes the methodology and the steps to be implemented in this project. It discussed the approaches as well the project development tools and techniques. The methodology can guide every phase of project development.
3.2 Project Methodology

Project methodology is a guideline to ensure that all project activities are organized. In order to get basic information about ergonomic factors associated with nurses’ posture while patient handling observations are carried out. The project started from planning, analysis, design, and implementation.

Chapter 4 is data collection. Data collection consists of develop questionnaire for patient handling. After data collection, analysis should be performed. In chapter 5 the proposed model and solution are developed and analyzed. Chapter 6 is the conclusion of the report and recommendation for future work. In continue the project methodology as shown in Figure 3.1 will be described.
Figure 3.1 Project methodology
3.2.1 Planning Phase

The objective of the project is defined based on problem statement. Project scope is also determined. Some researches on project background were done to finalize the methodology of the project.

3.2.2 Data Collection and Analysis

Data analysis answers the questions of what the result of the project will do and where and when it will be used. In this phase, few activities are carried out such as data collection and literature review.

3.2.2.1 Literature Review

The basic physical model of the forces at L4/5 material handling is studied. This basic model includes forces, reaction forces and distances. Different types of patient handling are studied. In literature review definition, guidelines, method of analysis, gathering data and evaluating the results and the design are identified.
3.2.3 Data Analysis

After obtaining the data and some data analysis the assessment model is used to determine the recommendations as a guideline for the supply chain of used patient handling devices at hospitals. This guideline can help the hospitals’ management to promote the methods used for cost effective available devices in patient handling.

3.3 Methodology Used

The methods used for implementing a research can be categorized into two broad group of conceptual and empirical. Conceptual researches are divided into theoretical and model deviation which designs a theory or model as a research or solving a problem. The empirical method can be a case study or a survey. The survey is done by research scientifically and it is based on all types of researches. The case study is done by collecting data from real systems and analyzing the data in order to get the conclusion. The mix-methodology is used for many projects which they do not use only one especial type of methodology but they use a mix mode of several types of them. It is easily understood that a mixed-methodology is needed to deal with both quantitative and qualitative data gathered by the use of case studies and technical documentations concerning evaluation, selection and specification. The other important factor which has led the researcher to this type of methodology is the nature of “organizational needs and issues” which has a mixture of both qualitative and quantitative nature. The reasoning method of this research is believed to be mainly based on induction because the desired outcome (i.e. a conceptual framework) does not answer a “yes-no” question or test a hypothesis but instead helps explain the questions which start with “why” and “how”. Mix-methodology is chosen for this project. The conceptual methodologies are used to determine the assessment methods for evaluating patient handling.
CHAPTER 4

DATA COLLECTION

4.1 Introduction

The most important focus of this study is to design a supply chain network for minimizing the costs of supplying the products needed in non-manual patient handling. First, we need to be sure that the problem of the nurses in patient handling is not related to factors except availability of the devices. For example the problem of the nurses can be the design of the devices or so on. In order to be sure in this study a questionnaire is developed and distributed in the nurses.

4.3 Questionnaire

There are some studies that use questionnaires to determine the level of low back pain among nurses and the problem led to more manual patient handling. Longitudinal studies were performed with a follow up at 1 and 8 years among nurses.
employed by a university hospital in Switzerland. A modified version of the Nordic Questionnaire was distributed to obtain information about demographic data, occupational activities, and various aspects of LBP and the potential problems. A clinical examination and several functional tests were used to overcome the problems associated with subjective pain reporting. Nurses having answered the questionnaire on all three occasions (n = 269) were classified into subgroups according to their pain intensity. For each subgroup the cause of LBP was recorded. Their results were LBP was highly prevalent with an annual prevalence varying from 73% to 76%. A large percentage (38%) indicated the same intensity of LBP on all three occasions. The proportion of nurses reporting repeated increase of LBP (19%) was approximately as large as the proportion who complained about repeated decrease of LBP (17%).

At last they conclude that it became evident that LBP poses a persistent problem among nurses. Over an eight year period almost half of the nurses indicated the same intensity of LBP, thus supporting a recurrent rather than a progressive nature of LBP. The questionnaire used in this study was a slightly modified version of the “Standardized Nordic Questionnaire”. A diagram was added to obtain information on LBP and other localized musculoskeletal disorders (LMD).

The following information was required:

a. Sociodemographic data: age, nationality, marital status.

b. General information on occupation and work load: hospital department, ward, seniority, degree, part time work, shift work, night work, frequent lifting, awkward working posture, repetitive movements, permanent standing or permanent sitting during work.

c. Leisure time activities: physical activity, regular fitness, or strength training.

d. Prevalence and duration of low back complaints: ever LBP, first occurrence of LBP, hospitalisation or job change due to LBP, duration of LBP within the preceding 12 months (0/1–7/8–30/>30 days/every day), effects on work and leisure time activities, sick
leave, medical history, current LBP, lifetime duration of LBP, problems due to LBP, and number of episodes.

e. Prevalence and duration of LMD according to assignment questionnaire: in the last part of the questionnaire a diagram was displayed. Disorders could be assigned to different parts of the body. Contrary to the binominal answer (yes/no) suggested by the “Nordic Questionnaire” the scale was modified using different categories (never/1–7/8–30/31–90/>90 days musculoskeletal disorders within preceding 12 months).

4.3.1 Designing the Questionnaires

Questionnaires were designed to assess the problems led to more manual patient handling at hospitals by health workers as shown in Appendix 1.

4.3.2 Analysis Data Gathered From Questionnaire

The questionnaire is designed to analyze the data using statistical elements such as mean, variance and frequency and percentages etc. In order to do that the questionnaire should be distributed among nurses in the hospitals. There are 5 specific hospitals under the same management which the questionnaires were distributed. There were 200 health workers as the sample of the test. This questionnaire wished to be a lead for this study as identifying the most important problem in hospitals in the view of the health workers associated with non-manual patient handling. The management of the hospital some years ago held the regular physical exercise classes for the health worker as free in order to increase the efficiency of patient handling. So in 200 health workers which has been questioned
166 of them had regular physical exercise in the week. So I limit the sample of the questionnaire to health workers whom:

- Their age is between 25-40
- Their weight/height index show that they are not in the category of fat people
- They are full-time workers (work for 5 shifts (8 hours shift) per week)
- Do not have previous back pain

The other categories which should be mentioned for these health workers are:

- Gender
- Years of experience
- Prefer ability of non-manual handling in contrast with manual handling

After gathering all the data from questionnaires the following results have come out:

<table>
<thead>
<tr>
<th>Years of Exprience</th>
<th>Sample Size</th>
<th>Having regular physical exercise</th>
<th>Not having regular physical exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10 (60)</td>
<td>(200)</td>
<td>Female (124)</td>
<td>Female(30)</td>
</tr>
<tr>
<td>10-20 (64)</td>
<td></td>
<td>Male (42)</td>
<td>Male(4)</td>
</tr>
<tr>
<td>0-10 (22)</td>
<td></td>
<td></td>
<td>0-10 (3)</td>
</tr>
<tr>
<td>10-20 (20)</td>
<td></td>
<td></td>
<td>10-20 (27)</td>
</tr>
<tr>
<td>0-10 (0)</td>
<td></td>
<td></td>
<td>0-10 (0)</td>
</tr>
</tbody>
</table>
In all the categories they prefer the non-manual patient handling rather than the manual one. And also all of the applicants have experienced pain while manual patient handling at least for one time except 2 of them in the first category which are 60. In total 161 mentioned lack of efficiency of the devices needed for patient handling (the less you need manual handling while the devices are available means more efficiency) as the most prominent problem in more manual patient handling at hospitals. Also, 21 persons mentioned lack of availability of the devices needed for patient handling (the less times you need a device for patient handling and it is not available means more availability). 14 persons mentioned limited types of available devices used in your hospital for helping health workers in patient handling. 4 persons mentioned limited capability of devices to decrease the hazards towards health workers’ health.

The detailed answers are as below:

(58)

(a): 6
(b): 49
(c): 3
(d): 0

(2)

(a): 0
(b): 2
(c): 0
(d): 0

(64)

(a): 2
(b): 11
(c): 41
(d): 10

(22)

(a): 2
(b): 18
(c): 0
(d): 2

(20)

(a): 2
(b): 18
(c): 0
(d): 0
These statistics show that without being effected with any other parameters health workers suffer from non-availability of devices used for patient handling and there are some hazards associated with their health while handling.
CHAPTER 5

MODEL DEVELOPMENT

5.1 Introduction

As the statistics show that for the non-manual handling tasks at hospitals the most prominent problem which causes more manual patient handling is non-availability of the devices needed for handling. 161 health workers among 200 health workers mentioned the non-availability of the devices as the most important problem. These people are the most percentage in all the categories which mean that without any other effect of other parameters the non-availability of the devices should be solved for non-manual patient handling as the prominent one. For this purpose this study will propose a model for the supply chain of the devices needed for handling in order to maximize the availability of the devices while decreasing the costs. This is possible with a multi-layer multi-period supply chain structure like as below.
5.2 Model Formulation

In this section the parameters and variables of the deterministic model are introduced and then the objective function and various types of constraints which are considered will be explained.

In order to get the maximum efficiency in using the devices of handling we should develop a multi-layer, multi-period supply chain model. The model should minimize the costs while maximize the availability of devices. In the next section this research describes the parameters, constraints and the objective function of the model. In this model we assumed that we have 5 hospitals sharing the handling devices.

5.2.1 Sets and Parameters

Sets for different types of facilities in the model are as follows:

i: Suppliers  
j: Plants(Patient handling devices production)  
k: Distribution Centers(between plants and hospitals)  
l: Hospitals  
m: Collection Centers  
n: Different type of products  
o: Raw materials  
p: Periods

Parameters for this model are defined as follows:

\( D_{inp} \): Demand of hospital \( l \) of product \( n \) in period \( p \)
\( t_{ijop} \) : Transportation cost of raw material \( o \) from supplier \( i \) to plant \( j \) in period \( p \)
\( t_{jknp} \) : Transportation cost of product \( n \) from plant \( j \) to center \( k \) in period \( p \)
\( t_{klnp} \) : Transportation cost of product \( n \) from distribution center \( k \) to center \( l \) in period \( p \)
\( t_{mnlp} \) : Transportation cost of product \( n \) from collection center \( m \) to hospital \( l \) in period \( p \)
\( t_{lmnp} \) : Transportation cost of product \( n \) from hospital \( l \) to center \( m \) in period \( p \)
\( t_{mjnp} \) : Transportation cost of product \( n \) from collection center \( m \) to plant \( j \) in period \( p \)
\( t_{ijrop} \) : Transportation cost of raw material \( o \) from plant \( j \) to plant \( j' \) in period \( p \)
\( t_{ijrn} \) : Transportation cost of product \( n \) from plant \( j \) to plant \( j' \) in period \( p \)
\( t_{kkmp} \) : Transportation cost of product \( n \) from center \( k \) to center \( k' \) in period \( p \)
\( R_{jno} \) : Units of raw material \( o \) needed to build product \( n \) in plant \( j \)
\( E_{oijp} \) : Price of raw material \( o \) of supplier \( i \) in factory \( j \) in period \( p \)
\( E_{np} \) : Price of product \( n \) in period \( p \)
\( C_{jnp} \) : Unit variable cost of product \( n \) in factory \( j \) in period \( p \)
\( F_i \) : Fixed cost of opening Supplier \( i \)
\( F_j \) : Fixed cost of opening plant \( j \)
\( F_k \) : Fixed cost of opening distribution center \( k \)
\( F_m \) : Fixed cost of opening distribution center \( m \)
\( H_{jnp} \) : Holding cost of product \( n \) in plant \( j \) in period \( p \)
\( H_{jop} \) : Holding cost of raw material \( o \) in plant \( j \) in period \( p \)
\( C_{rcm} \) : Cost of reworks in collection center \( m \) for product \( n \) in period \( p \)
\( C_{mc} \) : Cost of disposal in collection center \( m \) for product \( n \) in period \( p \)
\( C_{jnp} \) : Cost of reworks in plant \( j \) for product \( n \) in period \( p \)
\( C_{jnp} \) : Cost of disposal in plant \( j \) for product \( n \) in period \( p \)
\( C_{ih} \) : Cost of unmet demand for hospital \( l \) of product \( n \)
\( G_{im} \) : Percentage of product \( n \) that goes to collection centers from hospitals
\( G_{ml} \) : Percentage of defected product \( n \) that goes from collection centers to hospitals \( l \) after rework
\( G_{dm} \) : Percentage of products \( n \) which are disposed from collection centers
$G_{nj}^{dp}$: Percentage of products n which are disposed from plant j

$G_{nj}^{mj}$: Percentage of product n that goes to plant j from collection center m

$G_{nj}^{jk}$: Percentage of product n that goes to distribution centers from plant j

$O_{io p}^{Max}$, $O_{io p}^{Min}$: Maximum and Minimum Limits for raw material shipment from supplier

$I_{jo}^{Max}$: Maximum capacity for raw material inventory in plant j

$I_{jn}^{Max}$: Maximum capacity for product n inventory in plant j

$I_{kn}^{Max}$: Maximum capacity for product n inventory in distribution center k

$I_{j}^{o}$: Beginning inventory of plant j

$I_{k}^{o}$: Beginning inventory of distribution center k

$M_{jnp}^{p}$: Maximum production limit for product n in plant j in period p

$m_{jnp}^{p}$: Minimum production limit for product n in plant j in period p

$M^{sp}$: Maximum total production

$m^{sp}$: Minimum total production

$T_{io p}^{Max}$: Maximum transportation limit for raw material o from supplier i to plant j in period p

$T_{io p}^{Min}$: Minimum transportation limit for raw material o from supplier i to plant j in period p

$T_{jkn p}^{Max}$: Maximum transportation limit for product n from plant j to distribution center k in period p

$T_{jkn p}^{Min}$: Minimum transportation limit for product n from plant j to distribution center k in period p

$T_{kln p}^{Max}$: Maximum transportation limit for product n from distribution center k to hospital l in period p

$T_{kln p}^{Min}$: Minimum transportation limits for product n from distribution center k to hospital l in period p

$T_{lnmp}^{Max}$: Maximum transportation limit for product n from hospital l to collection center m in period p

$T_{lnmp}^{Min}$: Minimum transportation limit for product n from hospital l to collection center m in period p
$\gamma_{mnp}^{Max}$: Maximum transportation limit for product n from collection center m to hospital l in period p

$\gamma_{mnp}^{Min}$: Minimum transportation limit for product n from collection center m to hospital l in period p

$\gamma_{mjp}^{Max}$: Maximum transportation limit for product n from collection center m to plant j in period p

$\gamma_{mjp}^{Min}$: Minimum transportation limit for product n from collection center m to plant j in period p

$\gamma_{jip}^{Max}$: Maximum transportation limit for product n from plant j' to plant j in period p

$\gamma_{jip}^{Min}$: Minimum transportation limit for product n from plant j' to plant j in period p

$\gamma_{jop}^{Max}$: Maximum transportation limit for raw material o from plant j' to plant j in period p

$\gamma_{jop}^{Min}$: Minimum transportation limit raw material o from plant j' to plant j in period p

$\delta_{np}$: Maximum units of shortage of product n in period p

$\beta_{np}$: Maximum unit of backlog of product n in period p

$\delta_{n}$: Percentage of backorders that becomes lost demand for product n

5.2.2 Variables

Variables of the model are listed as below:

$\gamma_{ijop}$: Units of raw material o shipped from supplier i to plant j in period p

$x_{jkmnp}$: Units of product n shipped from plant j to distribution center k in period p

$x_{klnp}$: Units of product n shipped from distribution center k to hospital l in period p

$x_{lmnp}$: Units of product n shipped from hospital l to collection center m in period p

$x_{mnp}$: Units of product n shipped from collection center m to hospital l in period p
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\(x_{m_{jnp}}\) : Units of product n shipped from collection center m to plant j in period p

\(x_{j_{jn}}\) : Units of product n shipped from plant j to plant j' in period p

\(x_{j_{jop}}\) : Units of raw material o shipped from plant j to plant j' in period p

\(x_{kk_{jop}}\) : Units of raw material o shipped from distribution center k to distribution center k' in period p

\(W_{jnp}\) : Units of production in plant j of product n in period p

\(Z_{ip}\) : Integer variable, 1 if supplier i is open and 0 if it is not open

\(Z_{jp}\) : Integer variable, 1 if plant j is open and 0 if it is not open

\(Z_{kp}\) : Integer variable, 1 if distribution center k is open and 0 if it is not open

\(Z_{mp}\) : Integer variable, 1 if collection center m is open and 0 if it is not open

\(I_{jnp}\) : Inventory of plant j of product n at the end of period p

\(I_{jop}\) : Inventory of plant j of raw material o at the end of period p

\(I_{kn}\) : Inventory of distribution center k of product n at the end of period p

\(S_{lnp}\) : Shortage of hospital l of product n in period p

\(B_{lnp}\) : Units of demand backlog for hospital l of product n in period p

5.2.3 Objective function

The non-mathematical form of the objective function is developed for better understanding of different costs which are considered.

\[\text{Min} \left[ \text{Facilities Opening Fixed Costs} \right] + \left[ \text{Raw Material Procurement} \right] + \left[ \text{Production Variable Costs in Plants} \right] + \left[ \text{Transportation Cost from suppliers to Plants} \right] + \left[ \text{Transportation costs from plants to distribution centers} \right] + \left[ \text{Transportation cost from Distribution centers to customers} \right] + \left[ \text{Transportation cost from customers to collection centers} \right] + \left[ \text{Transportation cost from collection centers to plants} \right] + \left[ \text{Transportation Cost from Collection Centers to Customers} \right]\]
The Costs mentioned in total costs are as below:

\[ \text{Facilities Opening Fixed Costs} = \sum_p \sum_i z_{ip} F_i + \sum_p \sum_j z_{jp} F_j + \sum_p \sum_k z_{kp} F_l + \sum_p \sum_m z_{mp} F_m \]

which:

\[ \sum_p \sum_i z_{ip} F_i = \text{Opening Cost of Supplier i in period p} \]
\[ \sum_p \sum_j z_{jp} F_j = \text{Opening Cost of Plants j in period p} \]
\[ \sum_p \sum_k z_{kp} F_l = \text{Opening Cost of Distribution Center l in period p} \]
\[ \sum_p \sum_m z_{mp} F_m = \text{Opening Cost of Collection Center m in period p} \]

Raw Material O Procurement from supplier i for plant j in period p =

\[ \sum_i \sum_j \sum_o \sum_p E_{iop} Y_{ijop} \]

Production Variable Costs in Plant j for product n in period p = \[ \sum_j \sum_n \sum_p W_{jnp} C_{jnp} \]

Transportation Cost from supplier i to plant j for raw material o in period p =

\[ \sum_i \sum_j \sum_o \sum_p t_{ijop} Y_{ijop} \]

Transportation Costs from Plant j to Distribution Centers k for product n in period p

\[ = \sum_j \sum_k \sum_n \sum_p t_{jknp} x_{jknp} \]

Transportation Costs from Distribution Center k to hospital l for product n in period

\[ p = \sum_k \sum_l \sum_n \sum_p t_{klnp} x_{klnp} \]

Transportation Costs from Hospital l to Collection Center m for product n in period p

\[ = \sum_l \sum_m \sum_n \sum_p t_{lmnp} x_{lmnp} \]
Transportation Costs from Collection Center \( m \) to Plant \( j \) for product \( n \) in period \( p \) = 
\[ \sum_m \sum_j \sum_n \sum_p t_{mnp} x_{mnp} \]

Transportation Costs from plant \( j \) to plant \( j' \) for raw material \( o \) in period \( p \) = 
\[ \sum_j \sum_{j'} \sum_o \sum_p t_{jjop} x_{jjop} \]

Transportation Costs from Collection Center \( m \) to Hospital \( l \) for product \( n \) in period \( p \) = 
\[ \sum_m \sum_l \sum_n \sum_p x_{mlnp} t_{mlnp} \]

Transportation Costs from Distribution Center \( k \) to Distribution Center \( k' \) for product \( n \) in period \( p \) = 
\[ \sum_k \sum_{k'} \sum_n \sum_p t_{kknp} x_{kknp} \]

Transportation Costs from Plant \( j \) to Plant \( j' \) for product \( n \) in period \( p \) = 
\[ \sum_j \sum_{j'} \sum_n \sum_p t_{jjnp} x_{jjnp} \]

Inventory Holding Cost of Product \( n \) in Plant \( j \) in period \( p \) = 
\[ \sum_j \sum_n \sum_p H_{jnp} l_{jnp} \]

Inventory Holding Cost of Raw Material \( o \) in Plant \( j \) in period \( p \) = 
\[ \sum_j \sum_o \sum_p H_{jop} l_{jop} \]

Inventory Holding Cost of Product \( n \) in Distribution Center \( k \) = 
\[ \sum_k \sum_n \sum_p H_{knp} l_{knp} \]

Rework Costs in Collection Center \( m \) for product \( n \) in period \( p \) = 
\[ \sum_l \sum_m \sum_n \sum_p C_{mnp}^{rc} G_{mnp}^{ml} x_{lmpn} \]

Disposal Costs in Collection Center \( m \) for product \( n \) in period \( p \) = 
\[ \sum_l \sum_m \sum_n \sum_p C_{mnp}^{dc} G_{mnp}^{dp} x_{lmpn} \]

Rework Costs in Plant \( j \) for product \( n \) in period \( p \) = 
\[ \sum_m \sum_j \sum_n \sum_p C_{jnp}^{rp} G_{jnp}^{lk} x_{mnp} \]

Disposal Costs in Plant \( j \) for product \( n \) in period \( p \) = 
\[ \sum_m \sum_j \sum_n \sum_p C_{jnp}^{dp} G_{jnp}^{dp} x_{mnp} \]

Penalty Cost of Lost Demand for Hospital \( l \) for product \( n \) in period \( p \) = 
\[ \sum_l \sum_n \sum_p S_{lnp}^{ru} C_{lnp}^{ru} \]

This model uses a mixed integer linear objective function to minimize the total cost of supply chain network.

\[ \text{Min} \left[ \sum_p \left( \sum_l z_{lp} F_l + \sum_p \sum_j z_{jp} F_j + \sum_p \sum_k z_{kp} F_k + \sum_p \sum_m z_{mp} F_m \right) \right] + \]
\[ \sum_l \sum_j \sum_o \sum_p E_{ijop} Y_{ijop} \] + \[ \sum_j \sum_n \sum_p W_{jnp} C_{jnp} \] + \[ \sum_j \sum_o \sum_p t_{ijop} x_{ijop} \] + \[ \sum_j \sum_k \sum_n \sum_p t_{jknp} x_{jknp} \] + \[ \sum_k \sum_l \sum_n \sum_p t_{kknp} x_{kknp} \] + \[ \sum_j \sum_m \sum_n \sum_p t_{mnp} x_{lmpn} \] + \[ \sum_m \sum_j \sum_n \sum_p t_{mnp} x_{mnp} \] + \[ \sum_j \sum_{j'} \sum_o \sum_p t_{jjnp} x_{jjnp} \]
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+ [Σ_k Σ_{l',n} Σ_p t_{kn} x_{knlp} ] + [ Σ_j Σ_{l,n} Σ_p t_{jn} x_{jnlp} ] + [ Σ_j Σ_{l,n} Σ_p H_{jnlp} ]
+ [ Σ_j Σ_{l,n} Σ_p H_{jnlp} ] + [ Σ_k Σ_{l,lp} x_{lmnp} ] + [ Σ_m Σ_{l,lp} x_{lmnp} ]
+ [ Σ_l Σ_{m,lp} Σ_p R_{mnpl} C_{ij} x_{lmnp} ] + [ Σ_l Σ_{m,lp} Σ_p D_{np} C_{ij} x_{lmnp} ]
+ [ Σ_l Σ_{m,lp} Σ_p S_{lnp} C_{lnp} ]

As it can be seen from the objective function, in addition to basic features of supply chain network some other aspects are also included such as: cost of holding inventory, cost of reworks and disposal, cost of back logs and cost of lost demands.

5.2.4 Constraints

Different types of constraints are defined for the model to include most limitations of a supply chain network.

5.2.4.1 Demand balance equation

Σ_k x_{klnp} + Σ_m x_{mnp} + B_{lnp} + S_{lnp} = D_{lnp} + B_{ln(p−1)}

for l, n, p

Which: Σ_k x_{klnp} = shipment from distribution centers k to hospital l for product n in period p
Σ_m x_{mnp} = shipment from collection centers m to hospitals l for product n in period p

B_{lnp} = back orders of current period
\[ S_{\text{inp}} = \text{Lost Demands} \]
\[ D_{\text{inp}} = \text{Demand} \]
\[ B_{\text{inp}(p-1)} = \text{back order of previous period} \]

These constraints make sure that the products goes from plants and collection centers to hospitals plus back orders and unmet demand are equal to the hospital demand plus back order of last period.

\[ S_{\text{inp}} \ [\text{Lost demand of customer } l \text{ for product } n \text{ in period } p] = \]
\[ \delta_n \left[ \text{percentage of unmet demand that becomes lost order for product } n \right] \]
\[ \times \left( B_{\text{inp}(p-1)} \left[ \text{Back order of previous period for product } n \right] + \right. \]
\[ D_{\text{inp}} \left[ \text{Demand of current period for customer } l \text{ for product } n \right] \]
\[ - \sum_k X_{nktp} \left[ \text{shipment from distribution center } k \text{ to customer } l \right] - \]
\[ \sum_m x_{mtnp} \left[ \text{shipment from collection centers to customer } l \right] \geq 0 \]

\[ S_{\text{inp}} = \delta_n \times \left( B_{\text{inp}(p-1)} + D_{\text{inp}} - \sum_k X_{nktp} - \sum_m x_{mtnp} \right) \geq 0 \quad \text{for } l, n, p \]

Lost demand is equal to all unmet demand of the current period multiply by the percentage of unmet demand that becomes lost order.

### 5.2.4.2 Raw material balance equation

\[ \sum_n W_{jnnp} \times R_{jno} \left[ \text{Raw material } o \text{ used in plant } j \text{ for product } n \right] + \sum_j X_{jop} \left[ \text{Raw material } o \text{ shipped from plant } j \text{ to other plant } j' \right] + I_{jop} \left[ \text{Inventory of Raw materials } o \text{ in plant } j \right] = \]
\[ \sum_i Y_{ijop} \left[ \text{Raw material } o \text{ Shipped from supplier } i \text{ to plant } j \right] + \]
\[ \sum_j X_{jop} \left[ \text{Raw material } o \text{ received from other Plants} \right] + \]
\[ I_{jop}(p-1) \left[ \text{Inventory of previous period for raw material } o \right] \]

\[ \theta_{iop} \times Z_{ip} \leq \sum_j Y_{ijop} \leq \theta_{iop}^{\text{Max}} \times Z_{ip} \quad \text{for } i, o, p \]
Raw materials shipped to plants should be within maximum and minimum capacity of suppliers.

5.2.4.3 Product balance equation

First constraint is product balance equation for plants:

\[
\sum_{m} x_{mjn(p-1)} C_{nk}^{j} \text{ [Percentage of Defected product n shipped in from collection center m] } + W_{jn} \text{ [production of product n in plant j in current period] } + l_{jn(p-1)} \text{ [Inventory of product n in plant j in previous period] } + \sum_{j' \neq j} x_{jj'n} \text{ [products received from other plant j]} = \\
l_{jnp} \text{ [Inventory of product n in plant j in current period] } + \sum_{k} x_{jkn} \text{ [shipment to distribution center k from plant j]} + \sum_{j' \neq j} x_{jj'n} \text{ [shipment to plants j\' from plant j]}
\]

\[
\sum_{m} x_{mjn(p-1)} C_{nk}^{j} + W_{jn} + l_{jn(p-1)} + \sum_{j' \neq j} x_{jj'n} = l_{jnp} + \sum_{k} x_{jkn} + \sum_{j' \neq j} x_{jj'n} 
\]

for p, n, j

The second set of constraints is product balance equations for distribution centers:

\[
\sum_{k' \neq k} x_{k'kn} \text{ [shipment from other distribution center k to distribution center k\'] } + l_{kn(p-1)} \text{ [Inventory of product n in DC k of previous period] } + \\
\sum_{j} x_{jkn} \text{ [Shipment from plant j to DC k]} = \\
l_{kn} \text{ [inventory of product n in DC k in current period] } + \\
\sum_{l} x_{kl} \text{ [Shipment to hospital l from DC k of product n in period p] } + \\
\sum_{k' \neq k} x_{kkn} \text{ [shipment to other DC k\’ from DC k]}
\]

So
\[ \sum_{k\neq k} x_{ktkn} + I_{kn(p-1)} + \sum_{j} x_{jkn} = I_{knp} + \sum_{i} x_{kin} + \sum_{k\neq k} x_{kknp} \quad \text{for } k, n, p \]

\[ \sum_{p} [G_{np}^{lm} \times (\sum_{k} \sum_{i} x_{kin})] = \sum_{p} [\sum_{i} \sum_{m} x_{imnp}] \]

for \( n \)

Which:

\[ \sum_{p} [G_{np}^{lm} \times (\sum_{k} \sum_{i} x_{kin})] = \text{[Percentage of defected product } n \text{ shipped from distribution centers to hospitals in all periods]} \]

\[ \sum_{p} [\sum_{i} \sum_{m} x_{imnp}] = \text{[Shipment from hospital } l \text{ to collection center } m] \]

\[ \sum_{p} [G_{np}^{m} \times (\sum_{l} \sum_{m} x_{imnp})] = \sum_{p} [\sum_{m} \sum_{j} x_{mjnp}] \]

for \( n \)

Which:

\[ \sum_{p} [G_{np}^{m} \times (\sum_{l} \sum_{m} x_{imnp})] = \text{[Percentage of defected product } n \text{ shipped from hospital } l \text{ to collection center } m \text{ in all periods]} \]

\[ \sum_{p} [\sum_{m} \sum_{j} x_{mjnp}] = \text{[Shipment of product } n \text{ from collection center } m \text{ to plant } j] \]

\[ \sum_{p} [G_{np}^{m} \times (\sum_{l} \sum_{m} x_{imnp})] = \sum_{p} [\sum_{m} \sum_{l} x_{mlnp}] \]

for \( n \)

Which:

\[ \sum_{p} [G_{np}^{m} \times (\sum_{l} \sum_{m} x_{imnp})] = \text{[Percentage of defected product } n \text{ shipped from hospital } l \text{ to collection center } m \text{ in all periods]} \]

\[ \sum_{p} [\sum_{m} \sum_{l} x_{mlnp}] = \text{[Shipment from collection center } m \text{ to hospital } l \text{ for product } n] \]

### 5.2.4.4 Bounds on variables
In this section limitation of different variables are introduced:

Production limits:

\[ m_{jnp}^P \cdot Z_{jp} \leq W_{jnp} \leq M_{jnp}^P \cdot Z_{jp} \]  for j, n, p

Total production limit:

\[ m^{tp} = \text{[Minimum capacity of total production]} \]
\[ \sum W_{jnp} = \text{[Total production in all plants]} \]
\[ M^{tp} = \text{[Maximum capacity of total Production]} \]

\[ m^{tp} \leq \sum W_{jnp} \leq M^{tp} \]

Maximum available budget:

\[ \text{[Total investment of opening facilities]} \leq \text{[maximum available budget]} \]
\[ \left[ \sum_p \sum_i z_{ip} F_i + \sum_p \sum_j z_{jp} F_j + \sum_p \sum_k z_{kp} F_i + \sum_p \sum_m z_{mp} F_m \right] \leq M^b \]
Which:
\[ \left[ \sum_p \sum_i z_{ip} F_i + \sum_p \sum_j z_{jp} F_j + \sum_p \sum_k z_{kp} F_i + \sum_p \sum_m z_{mp} F_m \right] = \]
\[ \text{[Total cost of opening facilities]} \]
\( M^p = \text{[maximum available budget]} \)

The following set of constraints make sure that a facility which was opened in a previous period cannot be closed in a later period because the opening fixed cost of that facility is already paid:

\[
Z_{ip} \geq Z_{i(p-1)} \quad \text{for i, } p \neq 1
\]
\[
Z_{jp} \geq Z_{j(p-1)} \quad \text{for j, } p \neq 1
\]
\[
Z_{kp} \geq Z_{k(p-1)} \quad \text{for k, } p \neq 1
\]
\[
Z_{mp} \geq Z_{m(p-1)} \quad \text{for m, } p \neq 1
\]

for example if supplier 1 is open in period 2 (\( Z_{12} = 1 \)) it should be also open in period 3 (\( Z_{13} = 1 \)) so \( Z_{13} \geq Z_{12} \).

Transportation limits:

The following constraints consider the maximum and minimum limitations for transportation:

\[
\tau_{ijop}^{\text{Min}} * Z_{ip} * Z_{jp} \leq Y_{ijop} \leq \tau_{ijop}^{\text{Max}} * Z_{ip} * Z_{jp} \quad \text{for i, j, o, p}
\]
\[
\tau_{jknp}^{\text{Min}} * Z_{jp} * Z_{kp} \leq X_{jknp} \leq \tau_{jknp}^{\text{Max}} * Z_{jp} * Z_{kp} \quad \text{for j, k, n, p}
\]
\[
\tau_{kljp}^{\text{Min}} * Z_{kp} * Z_{lp} \leq X_{kljp} \leq \tau_{kljp}^{\text{Max}} * Z_{kp} * Z_{lp} \quad \text{for k, l, n, p}
\]
\[
\tau_{lmnp}^{\text{Min}} * Z_{lp} * Z_{mp} \leq X_{lmnp} \leq \tau_{lmnp}^{\text{Max}} * Z_{lp} * Z_{mp} \quad \text{for l, m, n, p}
\]
\[
\tau_{mijn}^{\text{Min}} * Z_{lp} * Z_{mp} \leq X_{mijn} \leq \tau_{mijn}^{\text{Max}} * Z_{lp} * Z_{mp} \quad \text{for m, l, n, p}
\]
\[
\tau_{mijn}^{\text{Min}} * Z_{lp} * Z_{mp} \leq X_{mijn} \leq \tau_{mijn}^{\text{Max}} * Z_{lp} * Z_{mp} \quad \text{for m, j, n, p}
\]
\[
\tau_{jjnp}^{\text{Min}} * Z_{jp} * Z_{jp} \leq X_{jjnp} \leq \tau_{jjnp}^{\text{Max}} * Z_{jp} * Z_{jp} \quad \text{for j, j, n, p}
\]
\[
\tau_{jjop}^{\text{Min}} * Z_{jp} * Z_{jp} \leq X_{jjop} \leq \tau_{jjop}^{\text{Max}} * Z_{jp} * Z_{jp} \quad \text{for j, j', o, p}
\]

Which for an example:

\( Y_{ijop} = \text{Transportation of raw material o from supplier i to plant j in period p} \)
\[ T_{ijop}^{\text{Max}} \leq \text{Maximum transportation of raw material o from supplier i to plant j in period p} \]

\[ T_{ijop}^{\text{Min}} \leq \text{Minimum transportation of raw material o from supplier i to plant j in period p} \]

This set of constraints indicate that transportation of raw materials and products are possible only if both origin and destination facilities are open (for example both \( Z_{ip} \) and \( Z_{jp} \) should be equal to 1 for first constraint.) and if both facilities are open the transportation amount is limited to minimum and maximum capacity of shipment \( (T_{ijop}^{\text{Min}} \leq Y_{ijop} \leq T_{ijop}^{\text{Max}}) \).

Maximum inventory levels:

\[ I_{jnp} \leq I_{jn}^{\text{Max}} \times Z_{jp} \quad \text{for j, n, p} \]

\[ I_{jop} \leq I_{jo}^{\text{Max}} \times Z_{jp} \quad \text{for j, o, p} \]

\[ I_{knp} \leq I_{kn}^{\text{Max}} \times Z_{kp} \quad \text{for k, n, p} \]

Which for an example:

\( I_{jnp} = \text{Inventory of product n in plant j in period p} \)

\( I_{jn}^{\text{Max}} \times Z_{jp} = \text{Maximum inventory level of product n in plant j} \)

This set of constraints indicates that only facilities which are open in period of time are able to have inventory levels. For example if plant 1 is closed in period 1 the value of \( Z_{12} = 0 \) so \( I_{112} \leq 0 \). And if the plant is open \( (Z_{12} = 1) \) the inventory would be limited to maximum capacity \( I_{112} \leq I_{11}^{\text{Max}} \).

**Maximum lost orders limitation:**

\[ \Sigma \text{Lost demand of hospital l of product n in period p} \leq S_{\text{Max}}^{\text{Max}} \times S_{\text{np}}^{\text{Max}} \quad \text{[Maximum allowable lost demand of product n for hospital l]} \]
\[ \sum_{t} S_{tnp} \leq S_{np}^{Max} \quad \text{for n, p} \]

Maximum back order limitation:

\[ \sum_{t} B_{tnp} \text{[Back orders of demands for hospital l for product n in period p]} \leq B_{np}^{Max} \text{[Maximum allowable back orders for product n in period p]} \]

\[ \sum_{t} B_{tnp} \leq B_{np}^{Max} \quad \text{for n, p} \]

**Designing test problems**

To get a strong benchmark for evaluation of proposed algorithm test problems with different sizes are solved. The sizes of the test problems which are considered by some researchers are also considered to determine the size of testing problems. For example Sabri and Beamon (2000) considered 2 different kinds of products, 3 suppliers, 4 wholesalers and 5 retailers. According to Wang et al. (2003) the testing has 2 kinds of products 2 wholesalers and 2 retailers. For each problem size different ranges for parameters should be defined. The values of these parameters are randomly generated based on upper and lower bounds. So we would have a better simulation for different situation in real world cases. The sizes considered for testing problems is listed in Table 5.1.
Table 5.1 Sizes considered for testing problems

<table>
<thead>
<tr>
<th>Problem Code</th>
<th>No. of suppliers</th>
<th>No. of Plants</th>
<th>No. of Distribution Centers</th>
<th>No. of hospitals</th>
<th>No. of Collection centers</th>
<th>No. of Products</th>
<th>No. of Raw Materials</th>
<th>No. of Periods</th>
<th>No. of Binary Variables</th>
<th>No. of constraints</th>
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</table>

For example problem code 1-2-2-1-2-1-2 represents a problem of one supplier, two plants, and two distribution centers and so on. Thus this will result in 162 numbers of constraints.

In this section a simple example of solved random case studies will be explained with more details. For this purpose we consider an example of a transfer assist devices manufacturing company in malaysia with problem code of 2-3-2-3-2-3-2-3.
For example the different type of products can be mentioned in our case:

Table 5.2: Transfer assist devices

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Name</th>
<th>Location</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>$S_1$</td>
<td>Johor Bahru</td>
</tr>
<tr>
<td>2</td>
<td>$S_2$</td>
<td>Kuala Lumpur</td>
</tr>
</tbody>
</table>

Table 5.3 – 5.10 show the name and location of facilities for this example.

Table 5.3 Suppliers’ Location

<table>
<thead>
<tr>
<th>Plants</th>
<th>Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$P_1$</td>
<td>Penang</td>
</tr>
<tr>
<td>2</td>
<td>$P_2$</td>
<td>Selangor</td>
</tr>
<tr>
<td>3</td>
<td>$P_3$</td>
<td>Kuala Lumpur</td>
</tr>
</tbody>
</table>
Table 5.5 Distribution Centers’ Location

<table>
<thead>
<tr>
<th>DC</th>
<th>Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$D_1$</td>
<td>Ipoh</td>
</tr>
<tr>
<td>2</td>
<td>$D_2$</td>
<td>Johor Bahru</td>
</tr>
</tbody>
</table>

Table 5.6 Hospitals’ Location

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$C_1$</td>
<td>Kuala Lumpur</td>
</tr>
<tr>
<td>2</td>
<td>$C_2$</td>
<td>Melaka</td>
</tr>
<tr>
<td>3</td>
<td>$C_3$</td>
<td>Singapour</td>
</tr>
</tbody>
</table>

Table 5.7 Collection Centers’ Location

<table>
<thead>
<tr>
<th>Collection Center</th>
<th>Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$R_1$</td>
<td>Johor Bahru</td>
</tr>
<tr>
<td>2</td>
<td>$R_2$</td>
<td>Ipoh</td>
</tr>
</tbody>
</table>

Table 5.8 Products’ Description

<table>
<thead>
<tr>
<th>Product</th>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$N_1$</td>
<td>Roller sheet</td>
</tr>
<tr>
<td>2</td>
<td>$N_2$</td>
<td>Transfer Belts</td>
</tr>
<tr>
<td>3</td>
<td>$N_3$</td>
<td>Slide/transfer boards</td>
</tr>
</tbody>
</table>

Table 5.9 Raw Materials’ Description

<table>
<thead>
<tr>
<th>Raw Material</th>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$M_1$</td>
<td>Sheet</td>
</tr>
<tr>
<td>2</td>
<td>$M_2$</td>
<td>Handle</td>
</tr>
</tbody>
</table>
Table 5.10 Periods

<table>
<thead>
<tr>
<th>Periods</th>
<th>Name</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(T_1)</td>
<td>1 July - 29 December 2011</td>
</tr>
<tr>
<td>2</td>
<td>(T_2)</td>
<td>1 Jan - 29 June 2012</td>
</tr>
<tr>
<td>3</td>
<td>(T_3)</td>
<td>1 July - 29 December 2012</td>
</tr>
</tbody>
</table>

The necessary inputs of this case are different type of costs, demand of hospitals and etc. These are shown in Table 5.11 - 5.17. The model uses the mentioned inputs to solve the model.

Table 5.11 Opening fixed cost of suppliers in different periods

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>150000</td>
<td>145000</td>
<td>140000</td>
</tr>
<tr>
<td>S2</td>
<td>155000</td>
<td>150000</td>
<td>145000</td>
</tr>
</tbody>
</table>

Table 5.12 Opening fixed cost of Plants in different periods

<table>
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<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
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<td>155000</td>
<td>150000</td>
</tr>
<tr>
<td>P2</td>
<td>165000</td>
<td>160000</td>
<td>155000</td>
</tr>
<tr>
<td>P3</td>
<td>170000</td>
<td>165000</td>
<td>160000</td>
</tr>
</tbody>
</table>

Table 5.13 Opening fixed cost of Distribution Centers in different periods

<table>
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<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>145000</td>
<td>140000</td>
<td>135000</td>
</tr>
<tr>
<td>D2</td>
<td>135000</td>
<td>130000</td>
<td>128000</td>
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Table 5.14 Opening fixed cost of Collection Centers in different periods

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<th>P3</th>
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</thead>
<tbody>
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<td>119000</td>
</tr>
<tr>
<td>R2</td>
<td>120000</td>
<td>119000</td>
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</table>
Table 5.15 Demand of hospitals for different transfer assist products in different periods

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<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitals</td>
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<td>N1</td>
<td>N2</td>
<td>N2</td>
<td>N2</td>
<td>N3</td>
<td>N3</td>
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<tr>
<td>C1</td>
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<td>470</td>
<td>290</td>
<td>570</td>
<td>580</td>
<td>250</td>
<td>410</td>
<td>310</td>
<td>500</td>
</tr>
<tr>
<td>C2</td>
<td>290</td>
<td>580</td>
<td>550</td>
<td>430</td>
<td>510</td>
<td>230</td>
<td>400</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>C3</td>
<td>590</td>
<td>540</td>
<td>540</td>
<td>390</td>
<td>310</td>
<td>310</td>
<td>540</td>
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</tbody>
</table>

Table 5.16 Variable Manufacturing costs of transfer assist products in different plants in different periods

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<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
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<td>N1</td>
<td>N2</td>
<td>N2</td>
<td>N2</td>
<td>N3</td>
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<tr>
<td>P1</td>
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<td>470</td>
<td>290</td>
<td>570</td>
<td>580</td>
<td>250</td>
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<td>430</td>
<td>510</td>
<td>230</td>
<td>400</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>P3</td>
<td>590</td>
<td>540</td>
<td>540</td>
<td>390</td>
<td>310</td>
<td>310</td>
<td>540</td>
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</table>

Table 5.17 Transportation costs from suppliers to plants for different raw materials in different periods

<table>
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<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
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<td>Raw Material</td>
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<td>M2</td>
<td>M2</td>
<td>M1</td>
<td>M2</td>
<td>M1</td>
<td>M2</td>
<td>M2</td>
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<tr>
<td>Plants</td>
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<td>P1</td>
<td>P1</td>
<td>P2</td>
<td>P2</td>
<td>P2</td>
<td>P2</td>
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<td>S1</td>
<td>S2</td>
<td>S2</td>
<td>S1</td>
<td>S1</td>
<td>S2</td>
<td>S2</td>
<td>S2</td>
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<td>2</td>
</tr>
</tbody>
</table>
The results of the model would be the facilities which should be opened in each period, the amount of the products or raw materials that are transported between facilities and etc. To illustrate these outputs a diagram is depicted for the transfer assist devices manufacturing company in Figure 5.1:

![Figure 5.1 Supply chain structure](image)

Figure 5.1 shows the supply chain structure which results in minimum total cost for this case. The black circles in the diagram indicate the facilities which are closed and the white ones are the working facilities. So for example the supplier located in Kuala Lumpur is chosen to be open and the supplier Johor Bahru is closed. The arrows in the diagram represent the transportation of products and raw materials between facilities. The amounts of transportation between each facility are shown in table 5.18 to table 5.21.
Table 5.18 Transportation of raw material from suppliers to plants in different periods

<table>
<thead>
<tr>
<th>Periods</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Material</td>
<td>M1</td>
<td>M1</td>
<td>M1</td>
<td>M2</td>
<td>M2</td>
<td>M1</td>
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<td>M1</td>
<td>M1</td>
<td>M1</td>
<td>M2</td>
<td>M2</td>
<td>M2</td>
</tr>
<tr>
<td>Plants</td>
<td>P1</td>
<td>P1</td>
<td>P1</td>
<td>P1</td>
<td>P1</td>
<td>P2</td>
<td>P2</td>
<td>P2</td>
<td>P2</td>
<td>P3</td>
<td>P3</td>
<td>P3</td>
<td>P3</td>
<td>P3</td>
<td>P3</td>
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<td>0</td>
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<td>0</td>
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<td>0</td>
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<td>0</td>
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</tr>
<tr>
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</tr>
</tbody>
</table>

Table 5.18 shows the transportations of raw material from suppliers to plants. For example in period 2, 6589 units of raw material M1 (sheet) is shipped from supplier S2 (Kuala Lampur) to plant P1 (Penang).

Table 5.19 Transportation of products from plants to distribution centers in different periods

<table>
<thead>
<tr>
<th>Periods</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products</td>
<td>N1</td>
<td>N1</td>
<td>N1</td>
<td>N2</td>
<td>N2</td>
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<td>DCs</td>
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<td>D1</td>
<td>D1</td>
<td>D1</td>
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<td>D3</td>
<td>D3</td>
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</table>

Table 5.19 Transportation of products from plants to distribution centers in different periods
Table 5.20 Transportation of products from distribution centers to hospitals in different periods

<table>
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<th>Periods</th>
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<th>T1</th>
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Table 5.21 Transportation of defected products from hospitals to collection centers in different periods

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CHAPTER 6

Conclusion and Future Work

6.1 Achievement

After going through the processes such as finding information from internet, referring to books and journal papers, a basic concept and theory of the research has been identified. Below are some main findings of the project.

1) Developing questionnaire among nurses of hospitals to identify the most problems associated with non-manual

2) Develop a multi-period multi-layer supply chain model to minimize costs while maximize the availability of the devices used in non-maual patient handling
6.2 Future Work

1) Designing the non-manual devices helping health workers for patient handling with less costs

2) Develop a stochastic model for supply chain of the hospitals

3) Using Genetic Algorithm in solving more sophisticated problems

6.3 Summary

Literature review assist in developing questionnaire in patient handling to identify the most prominent problem in more manual handling to help the hospital managers control the risks in availability of the devices helped in handling in order to have fewer injuries.

Questionnaire distributed among health workers helped to mention the most prominent problems in more manual patient handling. At last, the multi-period multi-layer supply chain model helped to minimize the total cost of the transfer assist devices for safer patient handling while increasing the efficiency of the devices used in handling the patients.
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List of Standards and Internet Links
Patient care ergonomics resource guide: safe patient handling and movement
www.visn8.med.va.gov/patientsafetycenter/

Nursing home initiative: getting to zero


OSHA
www.osha-slc.gov/SLTC/ergonomics/index.html

NIOSH
www.cdc.gov/niosh/topics/ergonomics/

New York State Public Employees Federation

Center for Occupational and Environmental Medicine
www.ErgonomicsInHealthcare.org

WING-USA: Work Injured Nurses Group
www.wingusa.org
Appendix 1
Questionnaires

General Information

1) Are you in the below group?
   Your age is between 25-40 & weight/height=not fat & full-time worker
   (work for 5 shifts (8 hours shift) per week) & no previous back pain
   ○Yes  ○No

   If yes please answer the following questions.

2) Gender:  ○Female  ○Male

Work experience

3) Years of working as a health worker:  ○0-10  ○10-20

4) Do you have any type of physical activity, regular fitness or strength training
   in your leisure time?
   ○ Yes  ○ No

Patient Handling Activities

5) Do you suffer from lower back or shoulder pain caused by manual patient
   handling even for one time in your working hours up to now?
   ○ Yes  ○ No

6) Do you prefer to use devices while patient handling rather than the manual
   handling?
   ○ Yes  ○ No
7) What is the most prominent problem in your mind which causes more manual patient handling at hospital?

a) Lack of efficiency of the devices needed for patient handling (the less you need manual handling while the devices are available means more efficiency)

b) Lack of availability of the devices needed for patient handling (the less times you need a device for patient handling and it is not available means more availability)

c) Limited types of available devices used in your hospital for helping health workers in patient handling

d) Limited capability of devices to decrease the hazards towards health workers’ health
Appendix 2
Captures of manual patient handling in Malaysia

Figure (a)

Figure (b)
Figure (e)