RFID enabled constraint based scheduling for transport logistics

Noppon Choosri

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Faculty of Computing, Engineering, and Technology
Staffordshire University,
Stafford ST18 0AD, U.K.

Abstract

This research aims to develop a realistic solution to enhance the efficiency of a transport logistics operation. The case study in this research is one of the largest agricultural suppliers in Northern Thailand. The cost of logistics in Thailand is relatively high compared to other countries, i.e. 11% of Gross Domestic Product (GDP) in 2007, and is particularly high in agricultural sector. The focus of the study is to enhance and improve transportation activities which typically account for the largest cost in logistics. The research is entitled 'RFID enabled constraint based scheduling for transport logistics '

The dissertation studies two important research components: 1) the data acquisition using Radio Frequency Identification Technology (RFID) for monitoring vehicles in a depot and 2) the scheduling by solving Constraint Satisfaction Optimisation Problem (CSOP) using Constraint Programming (CP). The scheduling problem of the research is to compose and schedule a fleet in which both private and subcontracting (outsourcing) vehicles are available, but to minimise the use of subcontractors.

Several contributions from this study can be identified at each stage of the study ranging from extensively reviewing the literature, field studies, developing the RFID prototype system for vehicle tracking, modelling and solving the defined scheduling problems using Constraint Programming, developing a RFID-CP based real time scheduling, and validating the proposed methods.

A number of validations are also carried out throughout the research. For instance, laboratory based experiments were conducted to measure the performance of the developed RFID tracking system in different configurations. Scenario tests were used to test the correctness of the proposed CP-based scheduling system, and structure interviews were used to collect feedbacks on the developed prototype from the case study company.

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Glossary

Term	Description
AC	Arc-Consistency
ACM	Association for Computing Machinery
AI	Artificial Intelligence
ANOVA	Analysis of Variance
API	Application Programming Interface
ASK	Amplitude-Shift Keying
Auto-ID	Automatic identification
B&B	Branch and Bound algorithm
BJ	Backjumping algorithm
BT	Backtracking algorithm
BV	Bound Value in B&B algorithm
CCTV	Closed Circuit Television
CEO	Chief Executive Officer
Cm.	Centimetre
CP	Constaint Programming
CSOP	Constraint Satisfaction Optimisation Problem
CSP	Constraint Satisfaction Problem
DGPS	Differential GPS
DSS	Decision Support System
EA	Evolutionary algorithm
EPC	Electronic Product Code
FCFS	First Come First Serve
FSK	Frequency-Shift Keying
GA	Genetic Algorithm
GDP	Gross Domestic Product
GIAI	Global Individual Asset Identifier
GIS	Geographic Information System
GLS	Guided Local Search
GPS	Global Positioning System
HF	High Frequency
HVRP	Heterogeneous VRP
IC	Integrated Circuit
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Thing
IP Camera	Internet Protocol Camera
ISO	International Standards Organization
IT	Information Technology
ITPP	Integrated Transportation Planning Problem
LF	Low Frequency

LP	License Plate
LPR	License-Plate Recognition
LTL	Less than Truck Load
M.	Metres
MCH	Min conflicts Heuristics
MDVRP	Multi-Depot Vehicle Routing Problems
MHz	Mega Hertz
mTSP	multiple Traveling Salesman Problem
NC	Node-Consistency
NESDB	National Economic and Social Development Board
NRI	Network Readiness Index
NRZ	Non-Return to Zero
PC	Path-Consistency
PIE	Pulse-Interval Encoding
PPS	Peuchpol Suvanabhum company
PSK	Phase-Shift Keying
QL	Qualititative
QN	Quantitative
QR Code	Quick Response Code
RCSP	Routing and Carrier Selection Problem
RF	Radio Frequency
RFID	Radio Frequency Identification
RIP	Randomized construction Improvement Perturbation
ROI	Return On Investment
SCM	Supply Chain Management
SD	Standard Deviation
SME	Small and Medium Enterprise
SRI	Selection, Routing and Improvement
TL	Truck Load
TS	Tabu Search
TSP	Travelling Salesman Problem
UCC	Uniform Code Council
UHF	Ultra High Frequency
VB.Net	Visual Basic.Net
VRP	Vehicle Routing Problems
VRPPC	Vehicle Routing Problem with Private fleet and Common carriers
WAAS	Wide Area Augmented System

Publications

CHOOSRI, N., YU, H. & ATKINS, A. S. Fleet scheduling in scarce resource environment using constraint programming. *The Mediterranean Journal of Computers and Networks,* in press.

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Chapter 1

Introduction

1.1 Introduction

The chapter discusses the background and motivation of this research and the aim, objectives and contributions are identified. The research methodology background and justification of the research approach adopted in the thesis are outlined together with the structure and the organisation of the contents.

1.2 Background and Motivation

Research evidence indicates that the cost of logistics in Thailand was relatively high compared to other countries, for instance, in 2007 the logistics cost in Thailand reached 11% of the Gross Domestic Product (GDP) while in Japan, Canada, U.S.A, the logistics costs are 5.1 %, 5.5 %, and 8.8 % respectively. Thailand has also been ranked 39th in a logistics competency ranking in 2010 (World Bank, 2010). This reflects the country's ability to be competitive in world markets. Classifying logistics cost by product categories, agricultural logistics production is the highest cost, and is similar to fertiliser, mineral and cement production respectively which contribute 19% of the GDP of Thailand (MOT, 2006).

Consequently, the most critical activity of logistic management is transportation as it general accounts for 25-50% of the total logistics cost (Perego et al., 2011, Lancioni et al., 2000, Swenseth and Godfrey, 2002). Transportation is associated with two costs outlined as follows: (Shapiro, 2001)

1) Flow cost which reflect a direct cost of product flow between facilities (e.g. mileage costs for vehicle travelling and contract carrier costs); and

2) Transportation resource costs which reflect an indirect cost i.e. cost of planning and managing flows (e.g. routing and scheduling cost and spare part cost)

It is apparent that a higher efficiency could be achieved when the fore mentioned costs are keep to a minimal. This is similar to global logistics transportation in which road transportation is the most used transportation (i.e. EU-27, U.S.A., in China road transportation contributed 45.6 %, 75 %, 72% respectively), in Thailand it occupies 83.8% of the entire transportation system (NESDB, 2010, MOT, 2006)). Therefore, this research is concentrated on improving road transportation logistics in Thailand.

In fact, besides Thailand, other countries also encounter the same challenges in transportation management, and this problem is a global issue that most firms in the world encounter. The challenge for the firms is to find some efficiency solution to handle their transportation issues to survive in business. There are a number of criteria to measure efficiencies, for example, 24% of goods vehicles are running empty and when carrying a load, vehicles are typically loaded at 57% of their maximum gross weight (World Economic Forum, 2009).

Information and Communication Technologies (ICTs) are the technologies that help execution activities faster, support autonomous decision making process, improve process transparency (Huang and Nof, 1999, Pokharel, 2005). A study by Byrd and Davidson (2003) has proved that ICT has a positive relation with logistical operation and the impacts of Integrating ICT to improve efficiency in logistics activities were also studied. Kapros et al. (2010) showed that ICT usage can allow vehicle utilisation to increase by 5.2 %. Another study by Rongviriyapanich and Srimuang (2009) showed that applying optimisation technique to transportation scheduling can help the case study retailer in Thailand to reduce their transportation cost by 4.2 %.

The ability to track the logistical progress and the effective decision are two important features of logistic management. This research involves integrating two high impact ICTs to achieve those identified features. The ICTs adopted in this research are Radio Frequency Identification (RFID), and optimisation technique to improve efficiency for a transport logistics application. RFID is one effective real time identification technology (Chapter 2.3). It plays a key role in providing transport information visibility for this research; also it incorporates a decision- making (optimisation) subsystem generating effective decision.

The decision-making subsystem of this research is also required as freight planning is a complicated and critical task. The problem requires logistics planners to answer many challenging questions in order to maximise profits to companies. For example, the typical questions may include ‘when should the products be delivered?’, ‘what are the techniques available to minimise cost or maximise profit?’, ‘how to assign heterogeneous trucks to the fleet?’, ‘what are the consequences if delivery plans change?’ etc. It is difficult to answer these questions effectively because the problem associated with them contains many constraints and factors such as the number of vehicles available, maximum capacities, delivery deadlines, route conditions, product characteristics, etc.

There are a number of methods for modelling an operational problem, i.e. transport logistics scheduling problem (in this research), to a computational problem. This research represents the problem using Constraint Satisfaction Optimisation Problems (CSOP) using Constraint Programming (CP) to solve this problem. The CP method has been identified to solve problems successfully (see Chapter 2.2.4).

This research is empirical research i.e. using a case study, and the observation indicates that most of the researches investigating ICTs in practical transportation are ‘public transportation’ problems (Perego et al., 2011). On the other hands, this research is focused on solving a ‘private transportation’ problem. The case study company is the agricultural logistics supplier in Northern Thailand.

A summary of the major motivations to conduct this research are as follows:

- Thailand logistics is under competitive, the personal interest of the researcher in investigating the problems, then proposing and developing solution to one of the high impact problems.
- To the best knowledge, there is no existing research implementing an integration of RFID technology with CP for agricultural transport in Thailand.

- The study of Kovavisaruch and Suntharasaj (2007) identifies that one of the key success factors for RFID adoption in Thailand is human resource development i.e. RFID researcher. This research can be part of the successful adoption of RFID technology in Thailand

The proposing solution of this research is defined based on the case study company as indicated in Chapter 5. The problem belongs to the class of problem that the company applied a Truck Load (TL) delivery system, using a single depot, having 2 choices of vehicles i.e. owned and hired vehicle, but owned vehicle are always preferable.

There are several research aspects to improving fleet transport efficiency. Also the issues have several variants subject to the strategies, business rules, and operation of each business. One of the classification schemes to classify a fleet problem is using the vehicle ownership for delivery which can categorise a fleet into 3 classifications 1) owned vehicle fleet 2) hired vehicle fleet (outsourcing) and 3) hybrid fleet. Kapros et al. (2010) investigated 98 firms(51 in Greece, and 47 in EU), and found that the proportions of the 3 types of fleet the firms adopt are 48 %,11.2%, and 40.8% respectively. The case study used in this research adopts the mixed fleet for the transport logistics operation in which an owned fleet is always preferable.

There is a clarification to be made with the term 'outsourcing' being used in this research. When the external services are used for logistics management, there are several levels of outsourcing services. The classification is using the 'PL' scheme; the PL Pyramid is demonstrated in Figure 1-1 (Vasiliauskas and Jakubauskas, 2007).

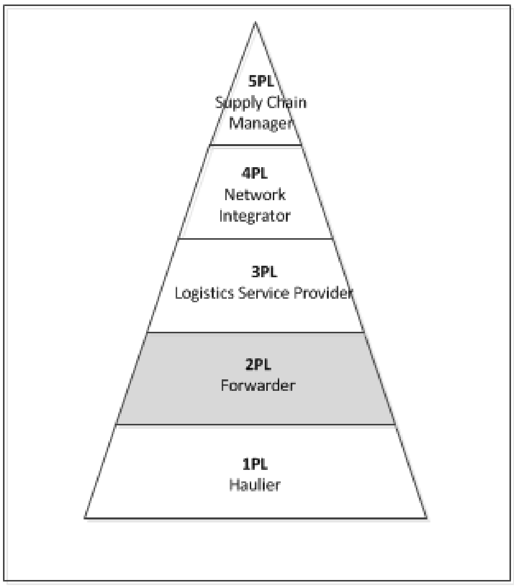


Figure 1- 1: PL Pyramid

Source: (Vasiliauskas and Jakubauskas, 2007)

1PL is using the owned vehicle for transportation, 2PL is using a single service or small number of functions from external firm i.e. transportation, 3-5 PLs are the external firms that provide more complicate services (more than 1 service i.e. transportation, warehousing, consultancy, etc.) in which 5 PL provides the holistic and complete service (Vasiliauskas and Jakubauskas, 2007). The subcontractor of the case study in this research is defined using the 2PL. Apart from the fleet ownership, there are also other characteristics uses to define the problem in logistics transportation such as whether the delivery is 'Truck Load (TL)' or 'Less than Truck Load (LTL) ?' 'Single depot or Multiple depots?' The problem in this research is the Truck Load (TL) using single depot. The full details of classification are discussed in Chapter 2.2.2, and the problem description of the case study is discussed in Chapter 4 and Chapter 5.

This research concentrates on investigating the potential applications of combining RFID technology and Constraint Programming optimisation methodology in transport logistics, particularly in agriculture logistics. The thesis addresses the following three research questions: 1) How can RFID technology be used in vehicle tracking and identification? 2) How to apply the Constrain Programming optimisation in transport logistics? and 3) Is there any potential in adopting combination of RFID technology and Constraint Programming in transport logistics? Those three research questions will be addressed in Chapters 3-5.

1.3 Aims and Objectives

This research aims to develop a realistic solution to enhance the efficiency of a transport logistics operation in an agricultural business in Thailand using two important technologies: RFID technology and the Constraint Programming optimisation-based methods.

To achieve the identified aim above, the followings are the objectives of this research which are outlined as follows:

- To review the transport logistics problems in general, and the specific challenges faced particularly in Thailand. (Chapter 2)
- To investigate the current practice of the case study company through field studies. (Chapter 5)
- To investigate the RFID technology and develop a laboratory-based RFID tracking system for transport applications. (Chapters 2 and 3)
- To conduct the laboratory-based experimentations to identify the good configuration to be applied in the case study. (Chapter 3)
- To study Constraint Programming (CP), and to find problem representation of CP for the case study problem. (Chapters 2 and 4)
- To develop a CP-based system to provide the decision support in transport logistics management. (Chapter 4)
- To investigate the holistic design of the integrated RFID-CP-based scheduling of the intelligent transport logistics system. (Chapter 5)
- To develop a laboratory prototype of a real time decision support system for the transport logistics system for the case study. (Chapter 5)
- To validate and evaluate the proposed method. (Chapter 5)

1.4 Contributions

The research contributes 4 major areas of contributions as follows:

1) In Chapter 2, extensive reviews are conducted towards 3 main areas that this research associates with, including road transport logistics, RFID technology, and Constraint Programming. The summary, classification, and analysis of these are made based on the reviews
2) In chapter 3, the research mainly involves applying RFID technology to vehicle tracking. The sub-contributions are:
   2.1 Identifying and solving issues in RFID middleware development for vehicle tracking applications
   2.2 Conducting experimental studies to measure RFID operations in different laboratory-based configurations
3) In chapter 4, the research investigates CP-based transport scheduling. The sub-contributions are:
   3.1 Constraint studies and problem representation including identification-related constraints, prioritising the constraints as 'hard' or 'soft' constraints, producing a formalism and defining an objective function
   3.2 Implementation of CP for fleet scheduling problems using the Choco Java constraint library based on the above formalism
   3.3 Conducting experimental study on optimal search strategies for the problem solving process
   3.4 Conducting experimental studies on functionality testing of the developed system in various scenarios
   3.5 Conducting an experimental study to investigate the applied problem solving method
   3.6 An analytical discussion of the benefits of the developed system
4) In chapter 5, the research studies the implementation of vehicle tracking and scheduling system for an agriculture company. The sub-contributions are:
   4.1 Field investigations to investigate the practical issues in agricultural transport logistics from the case study in Thailand

4.2 An holistic designed platform of RFID to enable real time support for optimal logistics decisions

4.3 Prototyping RFID to enable constraint-based scheduling for transport logistics

4.4 Using scenarios to validate the developed prototype in 4.3

4.5 A feedback investigation on the proposed method from the expert operators

4.6 An evaluation of the process flow by comparing the proposed method with the current operation

4.7 An analytical discussion of system transformation and expansion

1.5 Research Methodology

Terminologies and principles of the Figure 1-2 depicts research methodology applied to this research.

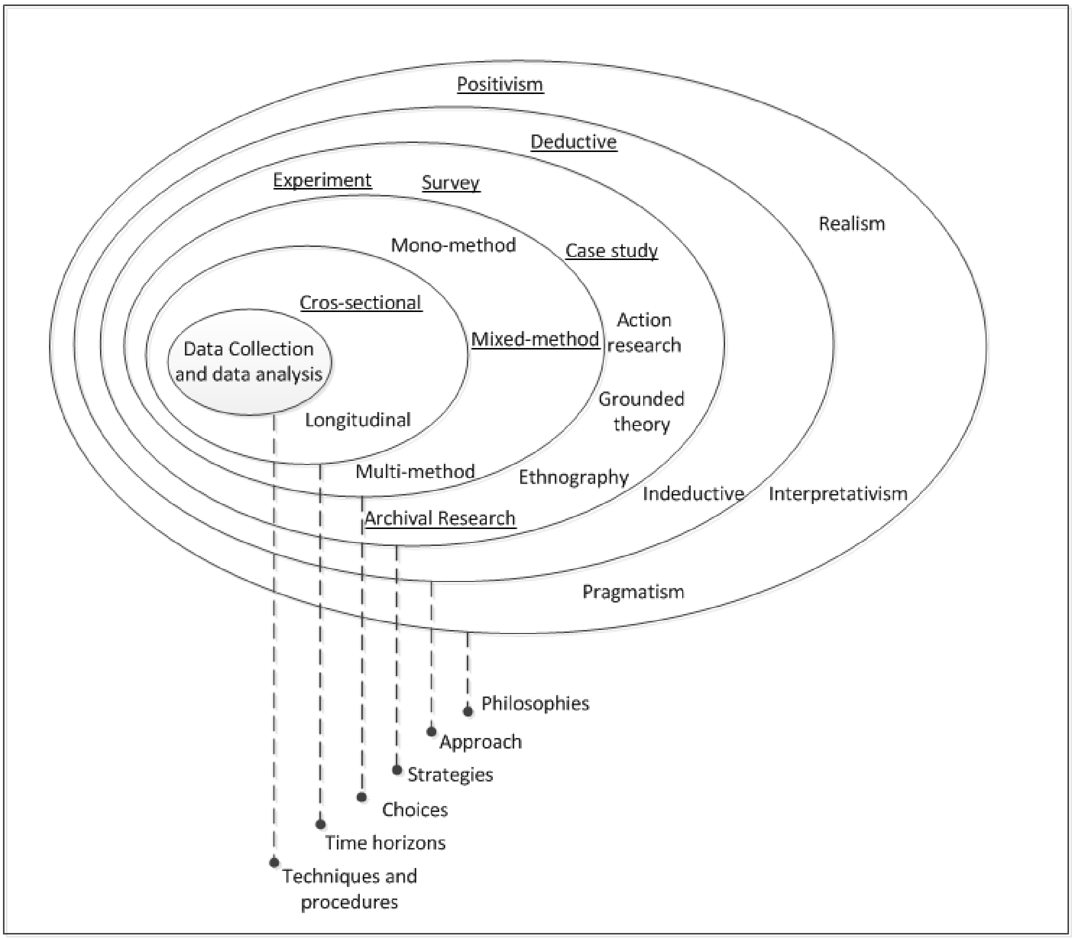


Figure 1- 2: The identified research method in 'Onion Diagram'

Source:(Saunders et al., 2009)

Research is stratified into layers and analogises with the layers of an onion (Saunders et al., 2009). The innermost layer (core layer) is the layer defining the procedures and techniques that each research deploys. However, the core layer is related to the other layers. The outermost layer is the Philosophies reflected how a researcher perceives a thing in the real world e.g. in an objective or subjective way. Next, is the Approach layer which indicates the purpose of research e.g. deductive (testing theory) or inductive (building theory). Then, the Strategy layer is the layer to define what bases apply to achieve the research aim. After that, there is a layer to define a choice of data collection and analysis techniques. When characteristics of 'quantitative' or 'qualitative' of data are considered, together with data collection technique, the research method can be classified as mono-method, multi-methods, and mixed methods. Mono method is the using of one data collection technique , multiple methods is the use of more than one data collection technique but each technique is either a quantitative or qualitative method, whereas a mixed method is using more than one data collection technique that can be a hybrid between quantitative and qualitative methods. And, the Time horizon layer is defined as the periods of time in conducting the research which are a cross-sectional (snapshot) or longitudinal (series of snapshots).

1.6 Research Framework and Strategies

The research is exploratory research. The diagram showing the research framework and strategies is depicted as Figure 1-3.The philosophy of this research is positivism as the depicted transport logistics process is an observable process, and the deductive approach is used to test the research question that RFID and CP-base optimisation can be integrated to improve the efficiency of the logistics transportation. The research is divided into 5 steps (Step 0 is an initial step) with top-down execution. There are several strategies involved throughout the thesis, and each step may be associated with more than 1 strategy. The description and justification of each strategy are as follows.

Archival research is a study involving a review of administration record and documents. This type of study is conducted at Step 0 for both a general understanding of the problem and investigating the macro transport logistics situations in Thailand. Also, it is applied in Step 1 to define and understand the problem of the case study.

A case study is defined as "a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence" (Robson, 2002). This research uses a case study to define the problem (Step 0). After that based on the problem definition studied, a solution is developed, and the case study is used again in the steps of validation and evaluation to measure the correctness of the proposed solution.

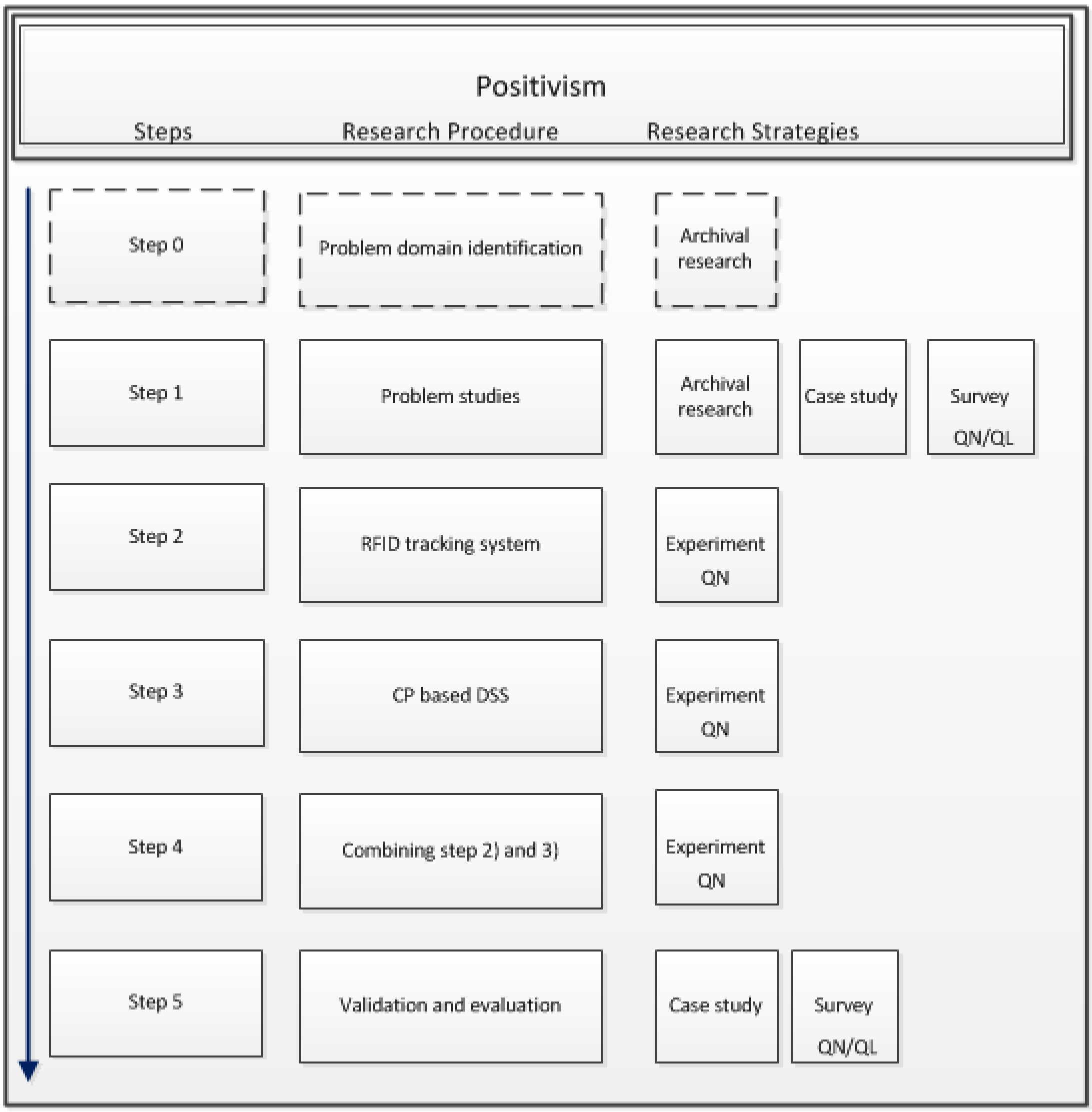


Figure 1- 3: Research Framework and Strategies Used

A survey is another strategy that the research employs, accompanied by the use of a case study. The semi-structured interview and observations are survey techniques that the research uses in the process of studying the problem, and the structured interview is the technique that this research applies in the stages of validation and evaluation.

Experiments are applied to the process of studying the impact of RFID configuration and the efficiency of the tracking system. Experiments are also used in the context of validity testing in this research to test the developed subsystem and system, such as the experiment on the CP based scheduling in Chapter 4, and the system validity evaluation in Chapter 5.

From the perspective of the data and processing techniques, the research is associated with both quantitative (abbreviated QN) and qualitative (abbreviated QL) methods .The survey study in Step 1 is for collecting data from the case study, some data having more qualitative characteristics by nature (e.g. problems, and company background and operation) and some are quantitative e.g. facts of operational data (vehicle capacity and tonnages). The prototype systems are developed based on the collected data. The experiments are conducted to measure the prototype using QN method analysis. A survey in the validation and evaluation process studies the feedback of the company in both QN and QL perspectives.

1.7 Thesis Structure

The thesis has 6 chapters sequentially discussed; the literature survey, RFID for vehicle tracking, CP-based transport scheduling, developing a tracking and scheduling system for an agriculture company, and a discussion on future work. The structure of the thesis layout is shown as Figure 1-4. The descriptions of each chapter are as follows.

Chapter 1 involves a discussion of the background and motivation, aim and objectives of the research, contributions of the research and the research methodology and the approach adopted in this dissertation.

Chapter 2 reviews the related principles and theories to provide the solid background in each area that this thesis focuses on. The review also provides a means to interrelate the focus of the study to other related research domains. There are 3 literature areas discussing: 1) RFID technology 2) Constraint Programming and 3) logistics transportation.

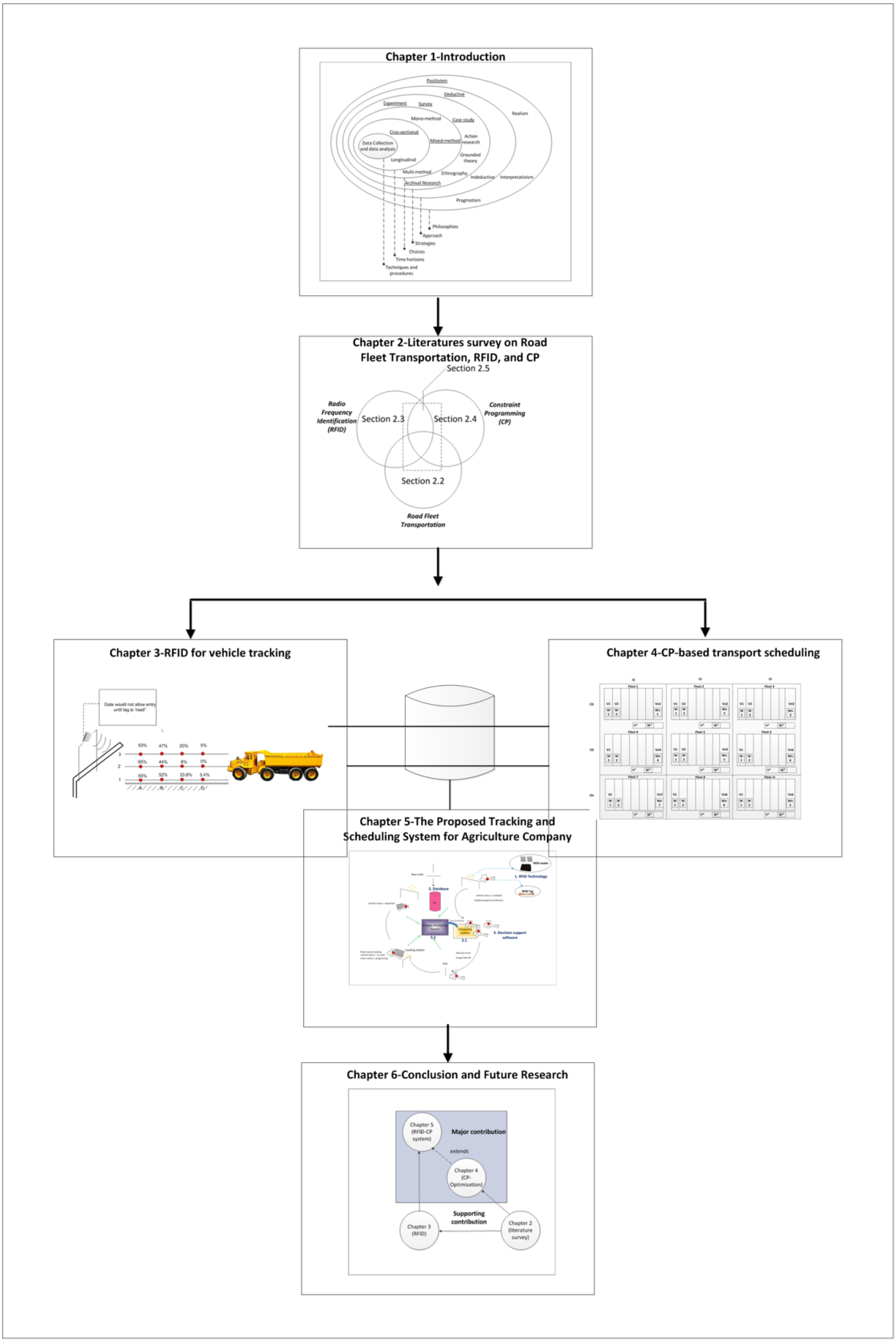


Figure 1- 4: Layout of the thesis structure

Chapter 3 investigates RFID technology and its use for vehicle identification. Some challenging issues are identified, and solutions are proposed to overcome the challenges. The laboratory-based system is developed to demonstrate and verify the proposed solution. Also, the developed system is used for conducting experiment experiments to investigate the impact of RFID configuration against the performance of the system.
Chapter 4 investigates an application of Constraint Programming (CP) for solving agricultural fleet scheduling for the case study company in Thailand. The main contents of the chapter include the modelling of real-life problems to CP representation, the demonstration of using a Choco, Java-based CP platform to solve the formulated fleet scheduling problem. It also includes the experimental studies for the purpose of optimal search investigation, validations, and observation on the problem solving method. In addition, the benefits of the developed method are discussed.

Chapter 5 discusses a development of a tracking and scheduling system for an agriculture company. In this chapter, the research discusses a process of engineering a real time decision system for logistics fleet scheduling starting from field observation to identify the inefficiency issues the company is facing. The chapter will also discuss several aspects of system development in integrating RFID technology for vehicle tracking (Chapter 3) with the CP (Chapter 4) for decision making. Validation and evaluation are conducted to measure the success of the proposed system. The system transformation and expansion are also discussed.

Chapter 6 is the closing chapter of this thesis. It summarises the process and findings of the research. The limitations of this research are discussed such that further studies can resolve any unsolved issues. Also, new research directions enabled by the research conducted here are identified.

Chapter 2

Literatures survey on Road Fleet Transportation, RFID, and CP

2.1 Introduction

The aim of this chapter is to investigate and review the 3 key areas conducted in this research which are the Road Fleet Transportation, Radio Frequency Identification, and Constraint Programming. The first area, the survey of the fleet transportation is to understand the role of transportation in the logistics system, to review the facts and statistics to perceive the current situation in particular in Thailand where this research is mainly conducted, and to realise the significance of IT to this issue. The second area, the survey of RFID technology is to understand the basic principles, capabilities and limitations of the technology, and the possible uses of RFID for logistics and general applications. The reviews of RFID technology also cover the current research issues with the proposed solutions from other researchers, and the comparative studies of RFID with other similar technologies. The third area, Constraint Programming (CP), is reviewed to investigate the basic principle, classification, algorithms and tools of the method, the applications of CP on real-world scheduling problems are also investigated. The overlap of 2 or more research areas defined above is investigated to identify the closer relationship to the research, and subsequently research novelty can be identified. The overview of the discussion of this chapter is depicted in Figure 2-1.

In the process of conducting the literature survey, the internet and the library are two main secondary data sources used. Literature on the academic publications was searched basically from 3 databases 1) *the Web of Knowledge* 2) *the IEEE Portal* and 3) *the Google Scholar using keywords.* The facts and statistics used in this chapter were gathered from several international institutes and local institutes in Thailand.

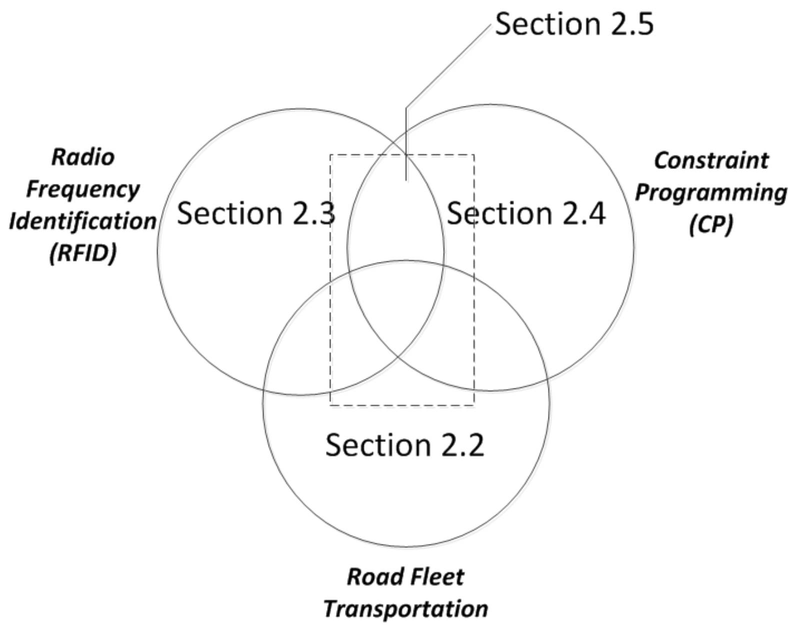


Figure 2- 1: Survey on Road Fleet Transportation, RFID, and CP

2.2 Logistics and Transportation Overview

There are closely interrelated relationships between logistics and supply chains. While a supply chain defines the series of activities and organisations that materials move through on their journeys from suppliers to final customers, logistics is the 'function' responsible for moving materials through their supply chains (Waters, 2007). The proper 'function' from the previous definition is clarified further using '8 Rs' which are "getting in the Right way, the Right product, in the Right quantity and Right quality, in the Right place at the Right time, for the Right customer at the Right cost" (Mangan et al., 2008).

A general production process starts from a company procuring raw materials to a production process, then storing finished goods at a warehouse, and moving goods to a depot or distribution centre to dispatch to customer. Every process that material passes through in a supply chain accumulates the costs of the product, and those costs tend to increase exponentially. Clearly, an effective logistics management strategies (i.e. minimising cost in supply chains) can reduce the cost of a product and enhance competitive advantages significantly. Transportation is the key activity in the logistics process, as it provides a means of moving material i.e. raw material, semi-goods, and goods from one location to the other and to end-customers. Also several studies claim that transportation accounts for 25-50% of the total logistics cost (Perego et al., 2011, Lancioni et al., 2000, Swenseth and Godfrey, 2002). In this research the focus is on the improvement of a fleet transportation activity which is the process of delivering finished goods from the depot to customers as indicated by the red dot in Figure 2-2.

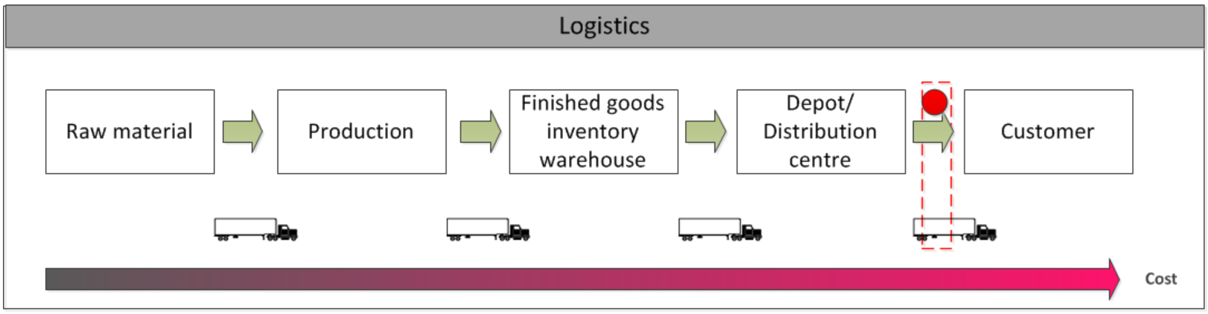


Figure 2- 2: Logistics Process and Transportation Activities

There are several means of transportation in logistics, but road transportation is the most used transportation globally as shown in Figure 2-3. In EU-countries (EU-27), USA, and China, road transportation were commonly used 45.6 %, 75 %, and 72 % respectively. Similarly, road transportation in Thailand also dominates the others, and this will be discussed in Section 2.2.4.

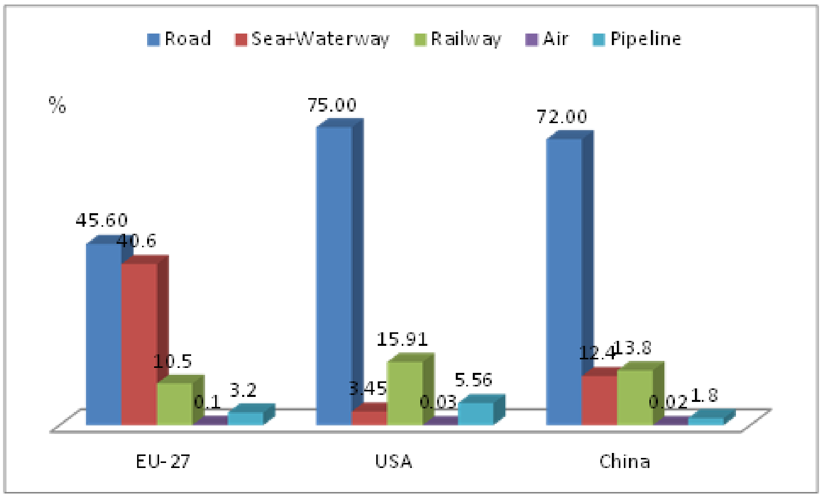


Figure 2- 3: Global Logistics Transportation

Source: Compiled from(European Communities, 2009, U.S. Department of Transportation and U.S. Department of Commerce, 2010, International Road Transport Union, 2009)

2.2.1 Significance of IT to Logistics

The '8 Rs' logistical target mentioned previously, the 'Rights' requirements indicate a crucial demand for information to support decision-making. Information Technology (IT), is comprised of hardware, software and people and is analogised with the eyes and ears (and sometimes partially the brain-to analyse information and suggest action) of logistics management (Chopra and Meindl, 2010). Effective IT in logistics management is the system that is able to supply quality information which is: accuracy, accessible timely, significant to decision, and shareable among stakeholders (Chopra and Meindl, 2010).

Statistically, the countries having a high rank in ICT adoption tend to be ranked in a high position of logistics competency. The vertical axis in Figure 2-4 indicates a ranking of the world logistics competencies in 2010 (World Bank, 2010), and the horizontal axis indicates an Network Readiness Index (NRI) of the same year (World Economic Forum, 2010) defined measurement of " how each country uses advantages of ICT and other new technologies to increase their growth and well-being" (World Economic Forum).

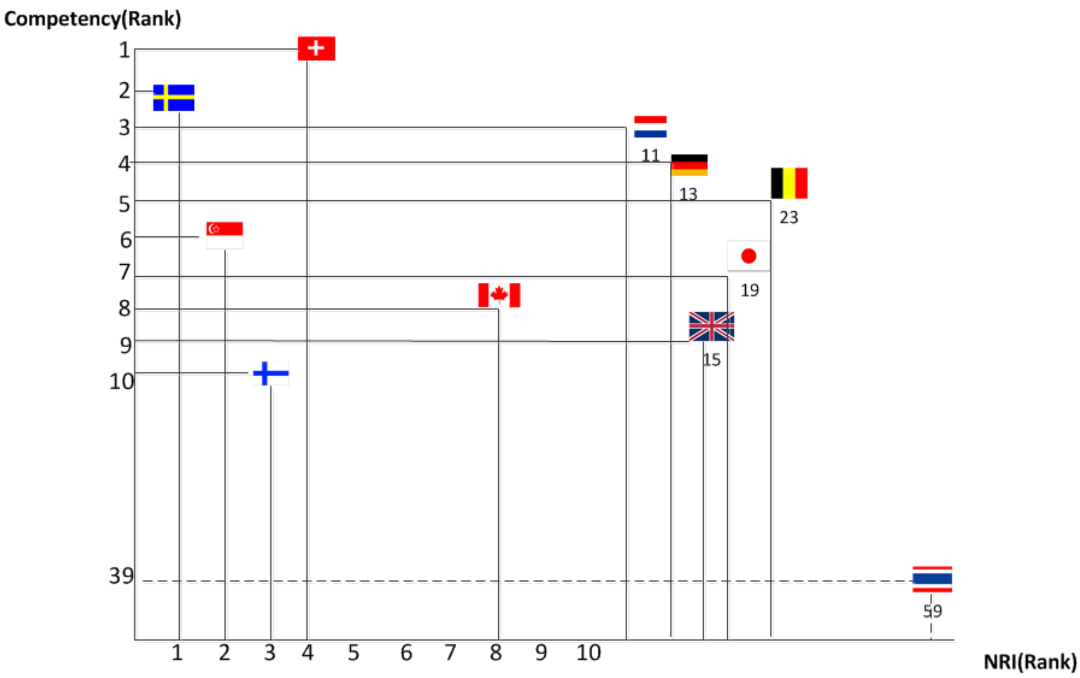


Figure 2- 4: Logistics Competency & NRI World Ranking

Sources: Compile from (World Bank, 2010, World Economic Forum, 2010)

The top 4 in term of NRI ranking include Sweden, Singapore, Finland and Switzerland and these countries are also ranked in the top-10 of the logistics competency index, while Thailand has been ranked the 59th for NRI, and the 39th for the competency index.

The impacts of Integrating ICT to improve efficiency in logistics activities were also studied. The ICT usage can allow vehicle utilisation to increase by 5.176 % (Kapros et al., 2010). Also a study by Rongviriyapanich and Srimuang (2009) showed that applying optimisation techniques for transportation scheduling can help retailers in Thailand reduce their transportation costs by 4.2 %.

2.2.2 Road Transport Logistics Problem Classification

The nature of a business separates the loading method into Full Truckload (TL), and Less Than Truckload (LTL). In TL, trucks will be assigned the full amount of products of a single customer to their capacities, and travel directly from a depot to the customer's premises. In contrast with LTL, trucks will not be assigned a full load of products of a single customer, so having space to serve multiple customers. Also, with LTL instead of loading products from a single depot, trucks can be assigned to pick up products from multiple sites for deliveries. In operational research, LTL problems are far more popular than TL. The LTL problems are usually the formulation of Vehicle Routing Problems (VRP) in which the concept of Graph Theory is applied to represent the problem i.e. each node represents the location that a vehicle visits to pick up or delivery goods, and the problems aim to find the optimal route and scheduling for visiting nodes. Eksioglu et al. (2009) provide the evidence to indicate the popularity of VRP that in 2009, at least 1,494 publications had been published, and from the first publication in the 1950s. The growth of VRP studies has been increased exponentially every year at the rate of 6.09%. However, the studies of the TL problems which are the characteristics of the transportation of the case study in this research have had less research attention.

Another criterion for a transport logistics problem is the number of depots which are single or multiple depots. In a single depot system there is only one depot, so there is no selection of depots required to dispatch the vehicles. Alternatively, the optimisation problems for multiple depots are the problems that require the extra challenges to find the optimal depot to service customers i.e. the nearest depot apart from solving vehicle scheduling and routing issues. When VRP formulation is adopted for multiple depot problems, the problem is defined as multi-depot VRP (MDVRP) as shown by the study of Mirabi et al. (2010).

Also, the number of vehicles in fleets of each problem can be different. Although, most of the transportation problems considered a fleet consisting of multiple vehicles (as well as this research), there is another class of problems that considers a fleet that has a single vehicle. The problem in this case mainly focuses on finding the optimal route of an individual vehicle, and the problem is known as the Travelling Salesman Problem (TSP). The TSP is intensively researched in Applegate et al.(2007). Furthermore, the multi vehicle fleet can be classified further into the homogeneous fleet where all vehicles are considered as the same type and heterogeneous where the vehicles in the fleet can be different types. Most VRP formulations use the assumption that fleets are homogeneous which rarely happened in the real-life applications (Hoff et al., 2010).

The problems can also be categorised by how vehicles are assigned to drivers and there are two types, driver-dependent vehicles, and driver–independent vehicles. In the driver-dependent vehicle system, a driver fully accounts for the vehicle (1 driver-1 vehicle), which means that scheduling vehicles also means scheduling drivers. In contrast, the driver-independent is the system where 1 driver can be assigned to drive any available vehicle independently. The fleet assignment in this scenario will require a scheduling of drivers and vehicles simultaneously (Laurent and Hao, 2007).

Fleet ownership is another important criterion to classify the transportation problem. Fleets can use 1) owned vehicles 2) hired (outsourced) vehicles and 3) mix owned and hired vehicles. There is usually a trade-off between using owned and hired vehicles. For instance, the fixed cost (vehicle cost and driver salary) of owned vehicles is relatively high, but using pure hired vehicles is not flexible. Therefore some companies, like the case study company, adopt a mixed fleet strategy for their transport operation.

2.2.3 Mixing Use of Internal and External Vehicle for Logistics Transportation

There are several literatures papers solving the transport optimisation problems when external vehicles are available as summarised in Table 2-1.

Table 2- 1: Literatures Related to Mixed Allocation Internal and External Vehicle

Publications	Named	Techniques	Studies
(Savelsbergh and Sol, 1998)	-	Branch-and-price	Solving real- life business (pickup and delivery service) using the Branch and price algorithm
(Chu, 2005)	-	Developed heuristics algorithm	Developing a heuristics search to solve a routing problem of owned vehicles, and selecting a service of a LTL courier
(Bolduc et al., 2007a)		Selection, Routing and Improvement (SRI)	Proposing a SRI algorithm and benchmarking the method studied in (Chu, 2005)
(Bolduc et al., 2007b)	VRPPC	Randomized construction Improvement-Perturbation (RIP)	-Proposing a perturbation meta-heuristics for VRPPC-Modelling VRPPC to a compatible heterogeneous fleet
(Zäpfel and Bögl, 2008)		Tabu Search/ Genetic Algorithm	-Driver factors are included(break and overtime) -Multi-period (week) -Comparing TS and GA solving the formulated problem -TS slightly outperforms over GA
(Cote and Potvin, 2009)	VRPPC	Tabu Search	Applying the Tabu Search to VRPPC
(Krajewska and Kopfer, 2009)	ITPP	Tabu Search	- 3 types of subcontractor can be chosen: tour based subcontractor, daily based subcontractor, and freight consolidation
(Ceschia et al., 2011)		Tabu Search	-Time windows considered -generalising the cost function for several costing systems of carriers -orders possibly remain unscheduled
(Kratica et al., 2012)	RCSP	Genetic Algorithm	-Using GA to solve RCSP and benchmark the method with (Chu, 2005) and (Bolduc et al., 2007a)

The common problems are similar with the same aim; to find the cost- optimal strategies of deliveries and outsourcing vehicles. Almost all have heterogeneous fleets (only the study of Cote and Potvin (2009) fleet was homogeneous due to a problem that was formulated under default VRPPC), single depot (except Savelsbergh and Sol (1998) using multiple depot). The studies of Savelsbergh and Sol (1998) and Zäpfel and Bögl (2008) were the only 2 papers based on real-life business problems, the rest only solved the artificial problems having the main purpose of testing their proposed algorithms.

Most of the studies were based on the single period assumption. The multi-period scheduling study (weekly based schedule) was conducted by Zäpfel and Bögl (2008). In the perspective of the applied algorithms, Tabu Search (TS) and Genetic Algorithm (GA) were popular for the recent researches, while some research focused on proposing new heuristics problems such as SRI algorithm (Bolduc et al., 2007a) , RIP algorithm (Bolduc et al., 2007b), and the heuristics algorithm proposed by Chu (2005).

One observation is that there is no problem definition that is widely accepted to define the problem previously mentioned. Several definitions propose the problem title such as "Vehicle Routing Problem with Private fleet and Common carriers (VRPPC)", "Integrated Transportation Planning Problem (ITPP)", and "Routing and Carrier Selection Problem (RCSP)", respectively.

In addition, the main discussion of this section as well as, this thesis is on the efficiency of logistics by considering transportation as a separate operation from the whole process. There is another view of tackling the problem by considering transportation and other processes as an integrated operation, and several of them became mature logistics philosophies that several enterprises have adopted. They are : 'lean production' which aims to eliminate wasteful operations of logistics (Christopher, 2007), an 'agile manufacturing'-quick production process through product customisation and reengineering (Shapiro, 2001), and 'cross-docking'- a distribution paradigm that avoids using warehouse to store products, but fast forward them to transfer among the vehicles (Waters, 2007).

2.2.4 Transport Logistics in Thailand

The research used a case study of a company in Thailand. In this section the broad view of logistics in Thailand was surveyed to provide an understanding of the situation in the country.

In 2004, the Office of the National Economic and Social Development Board (NESDB) Thailand indicated that Thailand had a commodity transport volume of approximately 500 million tons, comprising 183 million tons of imported-exported goods and approximately 317 million tons taken up by domestic transport (NESDB, 2004). Also there was an evidence indicated that the cost of logistics in Thailand was relatively high compared to other countries, for instance, in 2007 the logistics cost in Thailand reached 11% of the Gross Domestic Product (GDP) of the country (as shown in Figure 2-5). In classifying logistics cost by product categories, agricultural logistics incurs the highest costs, and is similar to fertiliser, mineral and cement production respectively which contribute 19% of the GDP of Thailand. In contrast, the lowest costs include seafood, medical equipment, electronic circuit boards, and jewellery products (MOT, 2006). These high percentage logistics costs have a significant effect on Thailand's trading competencies and hence product prices.

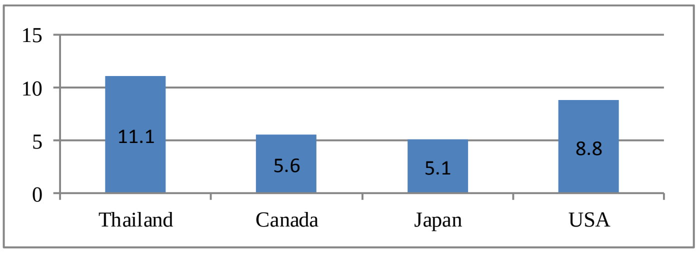


Figure 2- 5: Comparison of Logistics Cost in Different Countries

Source: (MOT, 2006)

Thailand uses five modes for domestic freight transportation: road, railway, ocean (sea), water (river) and air. However, road transport occupied 83.8% of the whole transportation in 2009 (NESDB, 2010, MOT, 2006) as outlined in Table 2-2.

Table 2- 2: Volume of Domestic Freight by Transport Mode

Mode	Year			
	2006	**2007**	**2008**	**2009**
Road	427.6	428.1	424.5	423.7
Railway	11.6	11.1	12.8	11.1
Ocean	30	30.7	29.9	29.3
Water	31.1	47.8	47.7	41.6
Air	0.12	0.11	0.10	0.10
Total	500.3	517.8	515.0	505.8

Unit: Million ton

Source: NESDB (2010) referred Ministry of Transport , Thailand

The reason that roads are used widely for logistics transportation in Thailand is possibly because roads constitute the largest transportation network in the country. Roads are also the only means of enabling door-to-door logistics delivery. Other modes of transportation such as maritime and rail still have limited usage due to lack of sufficient infrastructure support and, consequently, intermodal transportation is automatically disabled.

The National Economic and Social Development Board of Thailand and Chulalongkorn University Transportation Institute (NESDB and CU, 2007) reported the typical transport logistics problems found in Thailand as shown in Figure 2-6. The problems most frequently encountered in delivery are empty backhaul, late arrival, and a shortage of transport vehicles. These problems also reflect that logistics problems in Thailand are rooted in administration and planning problems.

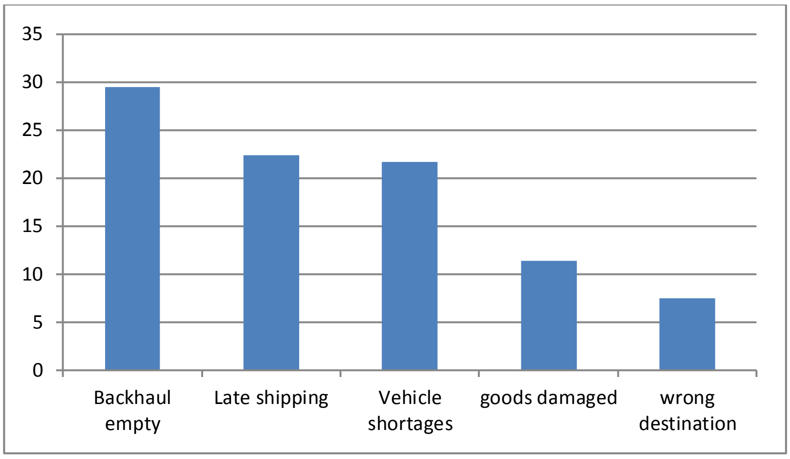


Figure 2- 6: Logistics Transportation Problems

Sources: (NESDB and CU, 2007)

Several major problems mentioned previously would be alleviated if logistics companies delivered products under an optimal plan only, applying another strategies such as 3PL if necessary. For example, to avoid loss from the empty backhaul problems, companies may schedule their freight so that each truck always has a load; freight consolidation or using sub-contractors may also help enable this strategy. Scheduling also has the potential to resolve vehicle shortage problems which in some cases are the cause of late delivery, for instance if a particular truck is required to serve a particular customer, its previous trip should not be such a long distance away that it cannot return in time.

2.3 Radio Frequency Identification Technologies

RFID is a contactless data identification system using radio frequencies as a carrier. The first known implementation of RFID dates back in World War II when the British military applied the system called Identification Friend or Foe (IFF) to determine whether incoming aircraft were friendly or hostile (Banks et al., 2007). In the past, the high cost of the devices and large size of their components impeded usage of RFID adoption for commercial applications. As the technology became more compact and cost-effective electronic technologies such as Integrated Circuit (IC), and microprocessors were introduced, the usage of RFID technology has become more widespread (Bhuptani and Moradpour, 2005). RFID started to gain popularity for commercial usage since the 1990s and is evidenced in a number of RFID applications implemented globally including livestock tagging, toll road payment systems, and the use of RFID on shop floors to direct the assembly of automobiles (Thornton et al., 2006). In the 2000's era, there are several indicators showing that RFID adoption is becoming main stream in global business solutions in many domains. For example, Wal-Mart has spent millions of dollars since the late 1990s researching the efficacy of RFID systems to replace barcodes (Sweeney, 2005). Also other business and everyday life situations have introduced new uses of RFID, for example, in a restaurant, RFID can be used to monitor freshness of the Sushi and providing more efficiency of billing operation (Ngai et al., 2008). In a grocery super market, a RFID shopping cart can be developed to enhance customer satisfaction e.g. locating desired products (Agarwal et al., 2011). In an amusement park, RFID can help locate missing children (Lin et al., 2010). In a zoo, RFID can be used to improve the efficiency of a ticketing system, and to enhance the experience of visitors (Choosri et al., 2010). In healthcare, (Hsu and Chen, 2011) RFID, combined with other sensors, can be used for monitoring the activities of the elderly and in a dairy farm, RFID can be used to track and schedule the milking cycle (Stankovski et al., 2012).

In order to make an RFID system operate properly, at least 3 components are required to integrate the system; that is, the Reader, Tags and Middleware as indicated in Figure 2-7.

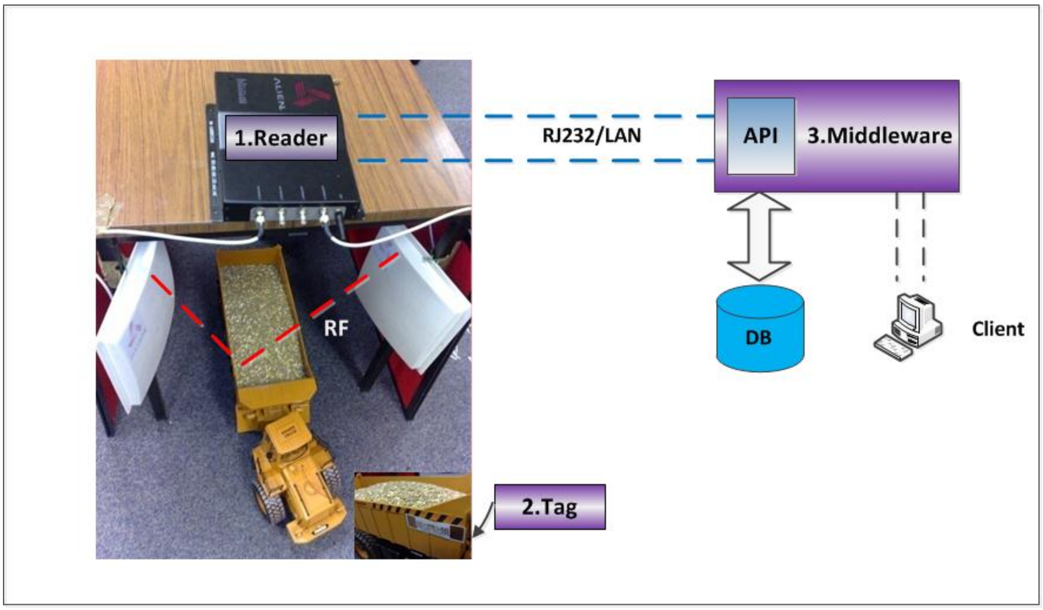


Figure 2- 7: RFID system

A tag is an electronic chip containing storage memory and which communicates with a reader via an antenna. The tags can be designed in many different formats. They might be glued to a package, clamped to a garment or even embedded in a person or animal. Tags are roughly divided into 3 types according to the source of power: active tags, passive tags, and semi-active tags. An active tag is the tag that supplies power to itself by using an on-board battery. The power of a passive tag is supplied by a reader, while a semi-active is a hybrid of active and passive – a tag also has the on-board power supply for its operation, but for transmitting its data, a semi-active tag uses the emitted power from the reader like a passive tag (Lahiri, 2006).

A reader or receiver is a device that sends instructions to the tag via Radio Frequency (RF), and it normally operates with a computer device. Although its primary operation is, as its name suggests, reading the tag, a write operation is also possible and there are several types of readers. For example, a stationary reader can be used for desktop computers, while a handheld reader is used for mobile computers such as PDAs. Handheld computers can also be used to extend the reading distance.

Middleware is an RFID component which provides the interface to associate with a reader. The primary functions of middleware are to control the identification processes such as reading and writing on a tag, and reader configuration. In practice, it is also typical that middleware provides further roles such as associating the acquired data to the backend database, and associating with user to supply identification results. Middleware is a computer application that communicate with a reader either by using a direct communication e.g. RS232, or using an Internet protocol e.g. TCP/IP.

The fact is that RFID is operated by Radio Frequency (RF) and each RF behaves differently. There are several frequencies utilised for RFIDs. A different frequency usually means different RF features (e.g. operating distance), and limitations (e.g. effecting environment). The specification of RFID in each frequency is indicated in Table 2-3.

Table 2- 3: RFID Specification

Band	Frequency	Typical Operating Distance			Effects	
		Passive	Active	Semi-Passive	Metal	Liquid
LF	125/134.2 KHz	Up to ~ 1 m.	-	-	/	
HF	13.56 MHz	Up to ~ 1.2 m.	-	-	/	
UHF	865-928 MHz	Up to ~ 6 m.	Up to hundreds m.	Up to ~4.5 m	/	/
Microwave	2.45 GHz a/ 5.8 GHz	Up to ~ 2 m.	Up to hundreds m.	Up to ~4.5 m	/	/

Source: Compiled from (Su et al., 2007, Khan et al., 2009)

From Table 2-3, it can be shown that RFID deploys different frequencies and contributes to different operating distances, which have different advantages and disadvantages. This can imply a suitability of application for each frequency. For example, a LF system can contribute only short operating distance but it is able to tolerate a highly humid environment. An application that is suitable for this frequency is animal/human auditing because the application does not need a long distance of identification, also the objects that the tag will be applied to are normally highly humid by nature e.g. blood and wet skin. Similarly, an UHF system can contribute a long operating distance e.g. 6 m. and can identify multiple tags at the same time, the system shall benefit to a logistics application. However, to maximise the performance of the system tags should avoid interfacing with humidity, and metal, as they can degrade the overall performance of the UHF system.

RFID Standards

For enhancing RFID applicability, a standard is required for making different organisations/users operate together. There are two important organisations having a high influence on issuing RFID standards which are The International Standards Organization (ISO) and EPCglobal.

ISO, founded in 1947, is one of the key international associations for standardizing equipment and operations (Jones and Chung, 2008). RFID is one of the domains issued by ISO, providing specifications. For RFID, ISO standards define 3 mainly aspects: 1) standards for the air interface specifications such as ISO 1800-(1-7) 2) standards for conformity tests such as ISO 18046-7 and 3) standards for a specification for applying RFID in particular application areas such as ISO 11784/85 for animal identification and ISO 21007 for gas cylinder identification.

EPCglobal Inc., founded in 2003, is a joint venture of GS1 and GS1 US (previously known as EAN International, and Uniform Code Council. Inc (UCC) respectively) (Jones and Chung, 2008). The primary goal of EPCGlobal is to issue standards for RFID adopters for a global Supply Chain. Unlike ISO, that in issuing RFID standards covers wide areas of applications i.e. there are air interface standards for every frequency utilised, the focus of the EPCglobal only issues the standard for the UHF frequency.

The ultimate goal of EPCglobal is to formulate an EPCGlobal Network in which members of the network (e.g. producers, retailers and customers) can interchange or access items of information through the 'EPC code' (Guenther et al., 2008). The Electronic Product Code (EPC) is a license-plate type identifier that can uniquely identify any item in a Supply Chain; the structure of EPC code consists of four parts including 1) Header to indicate EPC version used; 2) Manager Number to indicate a company name or a domain; 3) Object Class to indicate a class type of a tagged object; and 4) Serial Number to indicate an instance number of a tagged object (Lahiri, 2006): The structure of EPC is as Figure 2-8.

Header 8 Bits (0-7 Bits)	Manager No. 28 Bits (8-35 Bits)	Object Class 24 Bits (36-59 Bits)	Serial Number 36 Bits (60-95 Bits)

Figure 2- 8: EPC Structure
Source: Modified from (Lahiri, 2006)

EPC standard has evolved to Version 2 called EPC Gen 2 (the first version is called EPC gen 1). One of the major advantages of EPC Gen 2 is that the standard is recognised by ISO and also known as the ISO 18 000-6c(Hansen and Gillert, 2008). In Gen 1, a tag divides into 2 classes which are Class 0 is a tag that code is pre-programmed at the manufacturer, and

Class 1 which allows a tag to be programmed by an end user (write once, read many: WORM). In Gen 2, Class 0 and Class 1 of Gen 1 are merged into a single class called Gen2 Class1 (Jones and Chung, 2008) . In practise the advantage of EPC Gen 2 tags over the Gen 1 tags also include: 1) a faster read rate due to an improvement in the anti-collision characteristic of a tag; 2) enabling more advances tag queries; and 3) the tag can be killed and locked (Miles et al., 2008). The tags used in this research were EPC Gen 2 tag.

In addition, the EPC standard also provides interfaces to synchronise the code with other individual standards. The research considers integrating EPC with the Global Individual Asset Identifier (GIAI) which is a standard defined for enterprise asset items. With the view that the company can expand their business globally, the company vehicle might be required to have identifications from the enterprise. Applying a RFID tag with the vehicle will include the GIAI standard; this will be discussed in Chapter 3. The structure of the EPC data type of GIAI-96 is shown in Figure 2-9.

Header 8 bits	Filter Value 3 bits	Partition 3 bits	Company Prefix 20-40 bits	Item Reference 42-62 bits

subject to partition value
indicated in table 1

Figure 2- 9: GIAI-96 Structure
Source:(EPCGlobal, 2006)

2.3.1RFID in Logistics Management

The modern era of RFID that is emerging has the main target of improving efficiency of logistics management. It was found that RFID can be used to support almost every logistics activity for better performance. For example, in a manufacturing process, Tu et al. (2009) studied the efficiency improvement for mass customisation manufacturing, i.e. the flexible assembly process is needed to produce the customers required products. Bicycle manufacturing was used as a case study in which a RFID tag was proposed to be attached to each component of bicycle (e.g. frame) and boxes containing components. With the integration of Multi agent technology, the study estimated several efficiency indexes can be improved significantly. Poon et al. (2009) studied integrating RFID technology with Case

Base Reasoning for managing order-picking operations in a warehouse. The developed system was able to i) provide a guideline for choosing appropriate material handling equipment ii) identify the current location of resources and iii) formulate the shortest route for order-picking. Condea et al. (2012) investigated applying RFID technology to enhance automation for shelf replenishment in retail stores. The study investigated the bidirectional tracking of product movement between a store's backroom and sales floor under stochastic demand and product shrinkage. The error detection caused by imperfect RFID reading was also included in the study. Lee and Chan (2009) proposed a RFID-based intelligent reverse logistics system. The system not only applied a Genetic Algorithm (GA) to find the optimal location for the used-product collection point, but it also integrated RFID technology to the used products to increase the efficiency of the system. For example, at the collection point RFID can automatically count the quantity of products, and sending information to the product return centre to produce the pickup plan. At the product return centre information stored in a tag (i.e. product information) can be identified to transfer parts of a product to different production lines. Since the application of RFID for transportation management is the main focus of this research, the related literature will be discussed in Section 2.5.

2.3.2 RFID Research Challenges

A number of current publications on RFID applications covering both general and logistics applications were discussed in Section 2.3.1. There is another research society which concentrates its studies on improving the performances of RFID technology by trying to overcome the limitations of the current technologies and enhancing the system to meet real-life application requirements. The studies include: 1) improvement on tag features 2) improvement on reader features and 3) improvement on security.

The significance of a tag is as a component attaching to objects requiring identification. The improvement on tag features, therefore, can involve overcoming situations where tags meet unfavourable conditions when they are applied to certain material. For example, a UHF RFID holds the attractive feature on providing longer identification distance, but its limitation is that it is highly affected by water and metallic condition. Bjorninen et al.(2011)

investigated the UHF tag antenna design for curved surface with water containment i.e. bottle of water, and Park and Eom (2011) emphasised the study on designing tag for metallic surface environments. Another research focus is on minimising tag manufacturing cost, for instance Pranonsatit et al. (2012) contributed the low cost tag manufacturing techniques using typical ink-jet printer producing tags. Also, another improvement on tag production is the research on manufacturing the material embedded tag to enhance the flexibility of applying RFID in certain applications. Jeong and Son (2011) studied the embedded tag in a concrete floor. Ziai and Batchelor (2011) investigated the design of tattoo tags, on-skin tags, for human identification applications.

An RFID reader plays a primary role in transmitting communication signals to read or write the data of a tag. In a typical reader, only 1 frequency is operated, Mobashsher et al. (2011) proposed the antenna design that can integrate 3 frequency bands into the same handheld reader. Xunteng et al. (2011) researched the making of an energy-saving reader. Hsu and Yuan (2011) investigated the intelligent RFID reader having a feature of self-adaption to provide an optimal configuration for operating RFID in different environments which could have multiple readers in the system. Ren et al. (2012) proposed the antenna design of UHF RFID for Near Field identification, and an efficient tag anti-collision algorithm which can support a reader in identifying a tag faster by using variable length ID was studied by Yeo and Hwang (2010).

The improvement on security for RFID is an important issue as it is related to convincing prospective users on information safety to adopt the technology in everyday life applications. The basic requirement in every business application is that the information should be kept in some secured way to prevent unintended users from accessing the stored information. The basic operation of RFID is a reader that broadcasts query messages to tags, and tags that respond by sending their ‘stored information’ back to a reader. These communications shall be private, such that no unintended components can take advantage from the communication. The typical threat that can be incurred to RFID is given by Bank et al (2007) are *Eavesdropping, Spoofing, and Relay attack*. Eavesdropping is a threat that attempts to steal the ‘stored information’ from tags, or taking information ‘on-the-fly’, when tags transmit data to their intended readers. Spoofing is a threat that attempts to understand the communication protocol between a reader and a tag, then writing information to a new tag for some dishonest reasons. Relay Attack is an attempt at cloning the communication between a reader and a tag to repeatedly use it in illegal ways. The recent research focused on the improvement of RFID security includes: Armknecht et al. (2010) proposed an authentication method that allow tags disclosing their information-related identities to a reader. Hoque et al (2009) studied an authentication method that requires no persistent communication to the backend system for authentication between a tag and a reader. Lee (2012) focused the concern on investigating the security method for low cost RFID tags in which its computation power and memory are limited. Jin and Jin (2011) investigated the security solution for multi-reader problems. It was also observed that new security schemes have been proposed continuously, one of the current proposals was by Morshed et al. (2012) who proposed a hash-based protocol called Secure Ubiquitous Authentication Protocols (SUAPs). A summary of the research focusing on improving RFID technology in term of Tag performance: T, Reader performance: R and Security of the system: S is shown in Table 2-4.

Table 2- 4: The Studies Focused Improving RFID Performances

Publication	T	R	S	Studies
(Bjorninen et al., 2011)	/			Designing tag antenna for bottle of water
(Park and Eom, 2011)	/			Designing tag for metallic surface environment
(Pranonsatit et al., 2012)	/			Ink-Jet printed antennas for RFID tag
(Jeong and Son, 2011)	/			concrete floor embedded tag
(Ziai and Batchelor, 2011)	/			On-skin tag for human identification
(Mobashsher et al., 2011)		/		Triple band RFID reader antenna for handheld applications
(Xunteng et al., 2011)		/		Energy-saving reader
(Hsu and Yuan, 2011)		/		Self-configuration reader
(Ren et al., 2012)		/		Near Field identification UHF RFID
(Yeo and Hwang, 2010)		/		Anti-collision algorithm using variable length ID
(Armknecht et al., 2010)			/	Anonymous Authentication for RFID Systems
(Hoque et al., 2009)			/	Serverless Authentication
(Lee, 2012)			/	Authentication Protocols for Low-Cost RFID Tags
(Jin and Jin, 2011)			/	Security solution for multi-reader problems
(Morshed et al., 2012)			/	Secure Ubiquitous Authentication Protocols (SUAPs).

2.3.3 Other Related Identification Technologies

RFID can be considered as one of the Automatic identification (Auto-ID) technologies. Auto-ID in a general context is a means of identifying items and collecting data without human operations (Wyld, 2006) . There are several Auto-ID technologies as indicated in Figure 2-10.

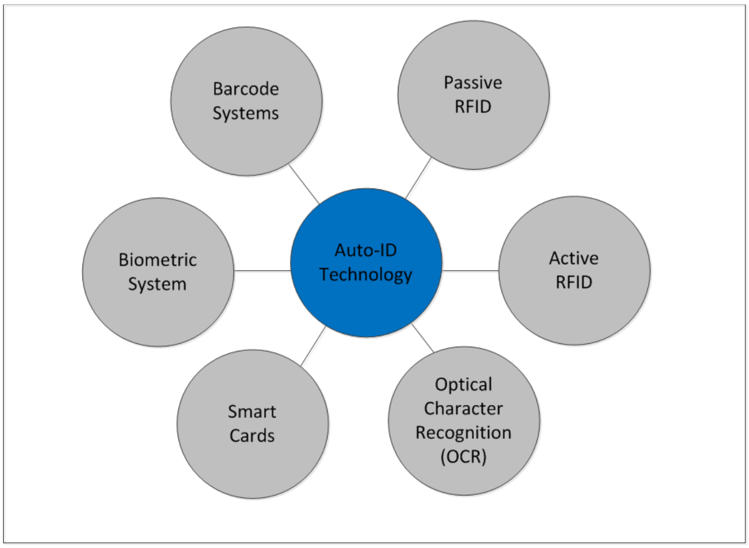


Figure 2- 10: Auto-ID Technologies

Source: (Wyld, 2006)

Most of the technologies indicated in Figure 2-10 hold some potential to be used for vehicle identification. The brief discussions on each of them are as follows:

1) Barcode

Barcode is an identification technology that principally using pattern alignments to indicate a uniqueness of the object. Currently, there are three types of barcodes: 1D-Barcoding, 2D-Barcoding and 3D-Barcoding.

1D-Barcoding is the foundation of other barcodes and uses adjacent bars and spaces of varying width to encode information to produce a unique identification and this is where the name barcode is derived from (Kato et al., 2010). The bar pattern is decoded using a barcode scanner which is functioned by shining a light across the code horizontally, and collect the reflected light to interpret a code (Kato et al., 2010, Michael and Michael, 2009).

2D-Barcoding is a modification of the 1D-Barcoding to enable more code to be generated. The bars and spaces of 1D Barcode are replaced by dots and spaces arranged in an array or a matrix, a barcode scanner of this requires an ability to read the code in two dimension-vertical, and horizontal simultaneously (Kato et al., 2010). A number of 2D barcode technologies have been proposed including Quick Response (QR) Code, Data Matrix, VeriCode, mCode, Trillcode, HCCB, and so on. QR Code and Data Matrix are two of the most widely adopted Barcoding approaches for mobile applications and both of them are granted the certification of the International Organization for Standardization (ISO) standard as ISO/IEC 18004, and ISO/IEC 16022) respectively (Kato et al., 2010).

While a 2D barcode has been maturely adopted, the concept of 3D barcoding is recently emerging, and there are at least two different efforts proposing another dimension to overcome certain aspects of 2 D barcode limitation from the literature. Alternatively, colour is proposed for expanding the capacities for identification as indicated in (Pei et al., 2008, Mayer et al., 2009, Simske et al., 2010), on the other hand, depth is an alternative parameter to produce 3D barcode. Instead of printing code on the label as with typical 1D and 2D barcode which is prone to be damaged, code is physically engraved/embossed on the identifying objects. There are several marking techniques, including laser marking, dot-impact marking, thermal marking and sandblast marking, and the method is alternatively called direct part marking (Kato et al., 2010).

2) GPS

GPS is shorthand for a Global Positioning System. It is widely used for identifying a position of objects on the earth. The identification result includes the current position of the object on a global referencing system. GPS is also commercially used in both vehicle navigation applications, known as satellite navigation system or Sat-Nav, e.g. Tomtom [www.tomtom.com], Garmin [www.garmin.com], Mio [http://eu.mio.com], Binatone [www.binatonesatnav.co.uk], Navigon [http://navigonsatnav.co.uk], etc., and vehicle tracking applications e.g. Quartix [www.quartix.co.uk], Crystall Ball [www.crystalball.tv], Tracker [www.tracker.co.uk], Navman Wireless [www.navman wireless.co.uk], Supa Track [www.supatrak.com], and etc.

GPS is operated by a constellation of 24 operation satellites. To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes. With this constellation geometry, four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of 10° is considered (El-Rabbany, 2002).

The system consists of three segments: the space segment, the control segment, and the user segment (Wells et al., 1999). The GPS system is shown in Figure 2-11.

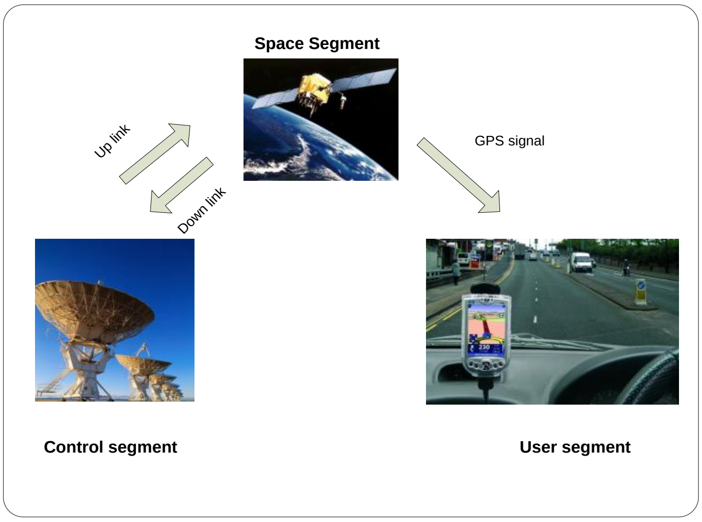


Figure 2- 11: GPS system

The space segment consists of a number of satellites transmitting signals from space. The operation of space segments is controlled by the ground control segment which has a master ground control station in Colorado, USA. A user segment includes both military and civilian users, which has the advantage of identifying any particular position on earth when holding a GPS receiver without any payment.

GPS, on its own, can deliver accuracy within a 15 meter range; however the corrected location of data sources are available in public to allow integrating them with GPS to enhance the accuracy of location identification. The two common sources include: 1) Differential GPS (DGPS) which can assist GPS deliver accuracy from 3-5 meters and 2) Wide Area Augmented System (WAAS) which can enhance GPS to achieve 3 meters of accuracy (McNamara, 2004).

3) License-Plate Recognition (LPR)

LPR is one of the OCR applications which use video to capture the license number of vehicles for monitoring, auditing, securities, surveillances, and decision supporting purposes. Video tracking applications require a video camera to capture object e.g. License Plate (LP) of vehicle in case of LPR. Caputo(2010) mentioned that currently there are two major types of video technologies which are analogue technology e.g. Closed Circuit Television (CCTV), and digital technology e.g. Internet Protocol Camera (IP Camera). In LPR, after a video camera is used to collect the real time plate data of a vehicle, data is sent to a recognition system to identify the vehicle, then the information can be applied to several applications e.g. logistics, parking management, security, surveillance depending on what backend application the system is associated with as shown in Figure 2-12.

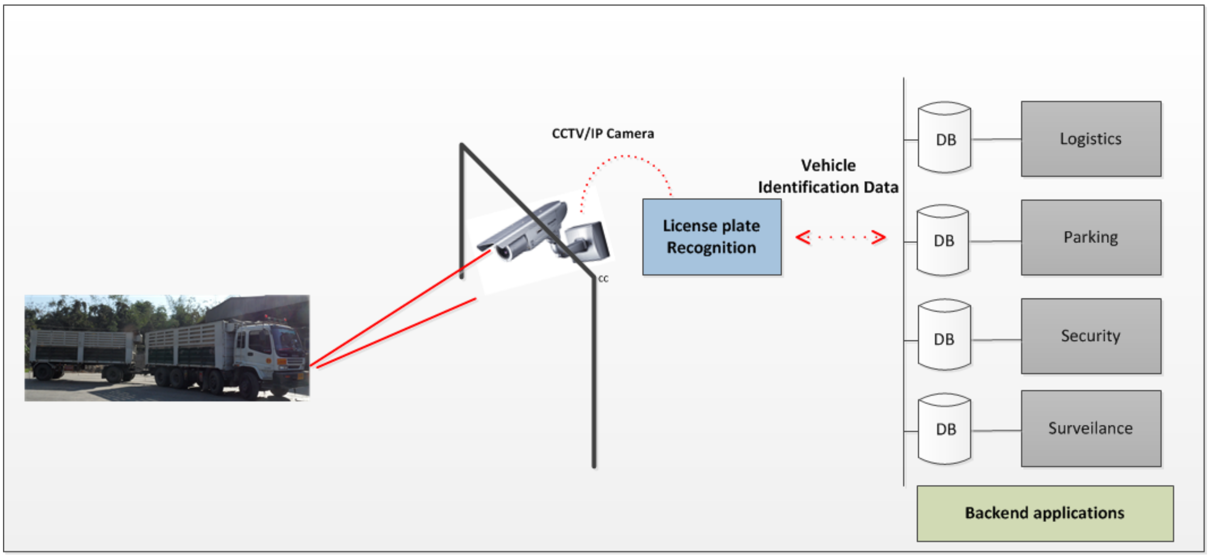


Figure 2- 12: LPR System

The general process of LPR consists of three sub-processing steps: 1) extraction of a license plate region; 2) segmentation of the plate characters; and 3) recognition of each character, and in each steps a number of algorithms and computation techniques have been proposed (2008). The license plate of each country is different, e.g. alphabet and layout, and holding different recognition challenge to be resolved. For example, in Thai systems, license plates are generally low quality license plates (i.e. plate is sometimes peeled off) and a great number of similar characters that exist in Thai alphabets (Sa-ngamuang et al., 2007). Also, Thai characters are unique i.e. to process a recognition to indicate a city name that the vehicle has registered (unlike English characters) are arranged in a three line level to make a word (Duangphasuk and Thammano, 2006). Some of the commercial LPR solution providers include: sagoss [www.sagoss.co.uk], ezCCTV.com [www.ezcctv.com], RF concepts [www.rfconcepts.co.uk], Genetec [www.genetec.com], and citysync [www.citysync.co.uk].

2.3.4 Comparison of RFID with the Other Identification Technologies

Table 2-5 indicates a comparison of five identification technologies, including UHF-RFID,1D barcode, QR code for 2D barcode, GPS and LPR, that are potentially eligible for tracking vehicles in a transport logistics application. The important criteria have been reviewed from both the literature and the current off-the-shelf high-end specifications. Table 2-5 indicates seven indexes to be considered for vehicle identification purposes which are outlined as:

1. **Distance:** Most of the identification technologies require a local communication between the receivers/sensors and data storages, and indicate a maximum distance that two sides can be apart. The longest range of communication is contributed by the LPR which can contribute up to 50 metres; the second best technology in this aspect is the UHF RFID technology, followed by the barcode technologies, GPS is not considered due to that it uses global communication between satellites and receivers.

2. **Identification Speed:** After a communication can be initialised, UHF RFID is the quickest identification technology followed by the barcode technologies and the most time-consuming identification is the LPR, in case of GPS this index defined the setting up time between receiver and satellite which highly depend on the weather conditions.

3. **Speed of Moving Object:** when the technologies are applied to track the moving objects. GPS is the most effective for tracking a very high speed moving object. An off-the-shelf review indicates that GPS can operate up to 1,000 knots (1,852 km/h), LPR and UHF-RFID can perform equally effective by allowing the moving objects to

be tracked up to 250 km/h, the barcode technologies are not quite so effective on the moving objects, and the most effective barcode devices can only contribute approximately 9 km/h.

4. **Line of Sight:** An index used to describe whether the technologies require a receiver and data storage media to be linearly aligned in the same coordination to enable a communication, the 1D barcode, 2D barcode and the LPR are optically identification based, therefore they require a line of sight. Alternatively, RFID and GPS use signal which can omni-directionally travel to transmit data, they require no line of sight.

5. **Concurrent Identification:** An index to indicate whether the technologies can identify objects simultaneously using one system, RFID is the only technology that can operate this feature which can allow thousands tags be identified in a second.

6. **Capacity:** An index indicates how much capacities the technologies can store data. UHF-RFID has the most capacity to store data as the off-the –shelf survey found that there is one supplier claiming that an UHF-tag can store up to 64 Kilobytes (KB) of data, a 2D barcode can store about 3 KB of binary data (for a QR code), and a 1D Barcode has very limited capacity to store up to 25 characters only. Not only RFID can provide larger storages, its storage can be partitioned for different purposes e.g. ID data and other data also which make RFID out-perform others technologies in term of data storage.

7. **Obstructers:** Factors that can impede performance of the technologies. Metal and humidity can degrade the performance of UHF-RFID technology. Barcodes are typically used in printed symbols to represent codes, and their readability can be reduced if the code is dirtied or damaged. The GPS receiver receives GPS signals from satellites, and a signal might be blocked by cloud, buildings, tree canopies, etc., and finally the recognition of LPR can be affected by rains, shadows and reflections.

Table 2- 5: Comparison of Identification Technologies for Vehicle Tracking

Technologies	Distances	Identification Speed	Speed of Moving Object	Line of Sight	Concurrent Identification	Capacity	Obstructers
UHF-RFID	Up to 10 metres	0.3 s	Up to 250 km/ h	No	Yes	Up to 64 KB	Metal/water
1D-Barcode	Up to 50 cm.	Up to 3.5 s	Up to 9+ km/h	Yes	No	20-25 Character	Dirt, damages
2D-Barcode(QR)	Up to 4 m	0.3	Up to 9+ km/h	Yes	No	Numeric 7089 character Alphanumeric 4296 character Binary 2953 Bytes	Dirt, damages
GPS	Global	Depend on conditions i.e. weather	Up to 1,852 km/h (1000 knots	No	No	_	Cloud, buildings, tree canopies
LPR	Up to 50 m	Up to 4 s	Up to 250 km/h	Yes	No	_	Rain ,Shadows and reflections

Sources: Compiled from (AlienTechnology, Tipdex.com, Barcodehq.com, Barcodesinc.com, von Reischach et al., 2010, Champtek, Barcoda, Arendarenko, 2009, Bosch, Zenco, 7id, 2011, esolutionscompany.com, microscan.com, Hyperdatadirect.com, Haicom, Trustedcomputinggroup.org, Fujitsu, Kato et al., 2010, Erabuild, 2006, Sweeney, 2005, McNamara, 2004, Ching-Tang et al., 2009, Friedrich et al., 2008)

Therefore, information from Table 2-5 justifies that UHF-RFID technology is the most appropriate data acquisition technology for vehicle identification since RFID can provide advantages over Barcodes on all performance aspects. It is considered to be superior to the GPS in the perspective that RFID allows data storage. Comparing RFID to LPR technology, RFID is less complicated and, requires no line of sight like the optical sensor. And RFID performance of the system does not depend on the natural environment as much as GPS and LPR.

2.4 Constraint Programming

Constraint programming (CP) is one of the well-rounded methods capable of tackling several kinds of classical and real-life application problems. The significance of the method in research societies is shown by the fact that the Association for Computing Machinery (ACM) has identified CP as one of the strategic directions in Computer Science research (Bartak, 1999). CP is a programming paradigm used for modelling and solving problems with a discrete set of solutions (Lozano, 2010). The idea of constraint programming is to solve problems by stating a set of constraints (i.e. conditions, properties or requirements) of the problems and finding a solution satisfying all the constraints using a constraint solver (Bartak, 1999, Rossi et al., 2006). The main advantages of CP are: declarative ability, generality, and adaptability i.e. constraints are considered independent and can associate each other (Hladik et al., 2008).

2.4.1 Constraint Classification

Constraint can be classified by the number of variable that the problem is associating with at a time (termed as "artity"): a single variable constraint is called "unary" constraint, and when 2 variables are considered, a constraint is called a "binary" constraint (Vermirovsky, 2003). For the case of non-binary CSPs, i.e., the CSP with constraints of arity larger than 2, it is widely known that they can be converted to an equivalent binary CSP (Bartak, 2001). So technically, most of the problems can be modelled in a binary constraint form.

Constraints can also be classified by the degree of restriction as a hard constraint that must not be violated, and a soft constraint that should not be violated. In CSP context, constraints are usually hard constraints. However, in several cases of CSP, the problem imposes 'over-constraints ' , and a solution cannot be produced, so relaxing some constraints as soft constraints is one way to solve a problem (Meseguer et al., 2006). While measuring the satisfaction of a hard constraint problem is to indicate that the variables are 'violated' or 'not violated', soft constraints are processed in slightly different way. Soft constraint processing is to measure the quantities of violations, and the minimal violation is the better answer (Hoeve and Katrie, 2006).

2.4.2 CP Classification

CP consists of 2 subclasses namely: the Constraint Satisfaction Problem (CSP), and the Constraint Satisfaction Optimisation problem (CSOP).

CSPs involve certain problem entities which are bound to each other by constraints. CSP is a problem composed of a finite set of 'variables', each of which has a finite 'domain', and a set of 'constraints' that restricts the values that the variables can simultaneously take. The problem is aimed to find out domains of variables that do not violate constraints that are associated with the variable (Tsang, 1993). Formal representation of CSP is represented below (Bouamama and Ghedira, 2006):

CSP is a triple (X, D, C); whose components are defined as follows where

X is a finite set of variables $\{x_1, x_2, ..., x_n\}$

D is a function which maps each variable in X to its domain of possible values, of any type, and D_{x_i} is used to denote the set of objects mapped from x_i by *D*. D can be considered as D = $\{D_{x1}, D_{x2}, ..., D_{xn}\}$;

C is a finite, possibly empty, set of constraints on an arbitrary subset of variables in *X*.

The well-known example of CSP is the n-queen problem, where one is asked to place n queens on the $n \times n$ chess board, where $n \geq 3$, so that they do not attack each other (Apt, 2003). Although, the discussion of this problem does not lead directly to the formulation of a transport scheduling problem identified in this research; it does provide a clear illustration of the principle of CSP theory and its use. A more realistic scheduling problem is discussed in Chapter 4.2 where CSP is used to formulate an employee 'rostering' problem.

The problem can be represented in a triple of (X, D, C) as:

1) X={X1,X2,X3,X4,X5,X6,X7,X8}

2) D={ Dx1={1,2,…8},Dx2 ={1,2,…8}, Dx3={1,2,…8}, Dx4={1,2,…8}, Dx5={1,2,…8}, Dx6={1,2,…8}, Dx7={1,2,…8}, Dx8={1,2,…8}}

3) The constraints (Apt, 2003).

for i ϵ[1,…n-1] and j ϵ [i+1,…n]

C= {C1, C2, C3}

C1: xi ≠ xj (no two queens in the same row)

C2: xi-xj ≠ i-j (no two queens in each South-West formulated diagonal)

C3: xi-xj ≠j-i (no two queens in each North-West formulated diagonal)

Figure 2-13 indicates a manual proof of the defined constraints above. When X_i and X_j represent positions of two queens in the chessboard having domain D_i and D_j to indicate the rows (columns) of the queens in the chessboard respectively.

a) indicates the scenario that the partial solution breaks C1 (i.e. X1=X2)

b) indicates the scenario that the partial solution breaks C2 (i.e. [1-2]=[1-2])

c) indicates the scenario that the partial solution break C3 (i.e. [7-6] = [2-1])

d) indicates the scenario that the all 3 constraints are satisfied

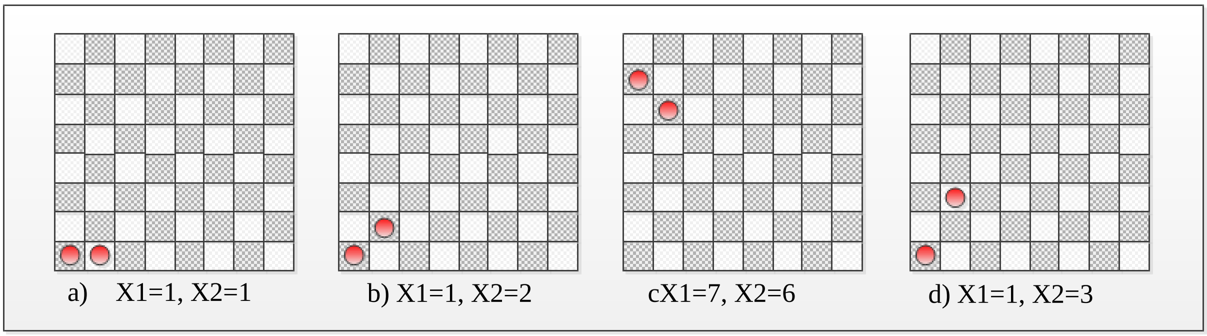


Figure 2- 13: Manual Proof of using Constraints for n-queen Problem

In CSP, It is typical that more than one feasible answer is produced, in this example, there are 92 feasible solutions and one of them is where the domain of X1,X2,….,X8 are {6,4,7,1,8,5,3} shown in Figure 2-14.

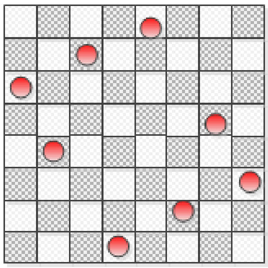


Figure 2- 14: One of the 92 Solutions of n-queen Problem
Source:(Apt, 2003)

CSP has a limitation in solving a class of problems in which the solutions of the problems are considered equally good e.g. the 92 solutions of the n-queen from the above discussion. However, in reality there are several constraint problems in which a quality of solution is measurable - one solution can be considered better than others, and one best particular solution is desirable to achieve (Tsang, 1993). The problems are the Constraint Satisfaction Optimisation problem (CSOPs).

CSOP is an ‘upgrade’ problem of CSP in the sense that solutions are not only feasible but also achieve optimality of an integrated cost function (Freuder and Mackworth, 2006). Formalism of CSP can be defined (Tsang, 1993).

As discussed previously when <X, D. C> define CSP, CSOP is <ƒ, X, D,C) where an optimisation (cost) function is added
When S = <X, D, C> defines a set of solutions of CSP
ƒ(S)→ minimum/maximum is the solution of CSOP

2.4.3 Search Algorithms for Solving CSP/CSOP

Many techniques and algorithms have been proposed for tackling CSP/CSOP and are outlined as follows:

Systematic search algorithm

The systematic search algorithm is a class of algorithms that explore the search space of a problem systematically, as the name suggests. Mostly, the method is also a tree-based search. The advantage of the method is that it can definitely identify whether a solution exists, and can guarantee producing answers if they do exist. One of the best known algorithms is the Backtracking (BT) algorithm where the related variables that are associated with the defined constraints are instantiated and checked in order. If there is no domain value of a variable that can satisfy the constraints, the search is backtracked to the most recently instantiated variable that still has alternatives available. The backtrack mechanism allows the search space to be pruned, however the method cannot avoid a problem called 'thrashing' which involved repeatedly exploring the same failure conditions that are already detected (Freuder and Mackworth, 2006) .

To tackle the constraint problems systematically, there are 2 important techniques to integrate with the BT to enhance a search performance firstly *consistency techniques,* and secondly propagation techniques. Applying BT alone, a search is 'blind' in a sense that satisfaction unsatisfied domain can't be detected beforehand. Thus consistency techniques are used to overcome that limitation by eliminating many unsatisfied domains of the variables at the very early stage. Therefore, it can be used to reduce the problem size significantly. There are several consistency processing levels; a unary constraint requires a Node-Consistency (NC) algorithm, a binary constraint requires an Arc Consistency (AC) algorithm where 2 variables are represented by 2 nodes with an arc connect to each other, if they are consistency, and Path Consistency (PC) is for checking the consistency of 2 or more arcs.

The *Constraint propagation* technique is a technique applying consistency techniques further in the sense that the effect of consistency checking is applied to any constraints that are associated with that variable (Zibran, 2007). For most of the cases, this can resolve 'thrashing' and make traditional BT behaves more intelligence. For example, a Backjumping (BJ) algorithm is one of the algorithms that applied the 'look back' scheme of constraint propagation. The processing of BJ is when BJ detect inconsistency, instead of backtracking for one level like BT, it analyses the source of inconsistency and backtracks to that level of the tree (Bartak, 1999). Obviously, this ability to 'jump' several levels can reduce search space and improve a search time when comparing to a typical backtracking algorithm. Another example is the use of 'look forward' to improve the search. A Look Forward algorithm does not perform consistency checking between instantiated variables but it does operate arc consistency check between an instantiated variable and un-instantiated variable, and a future variable, to avoid future inconsistency (Bartark, 2005).

Branch and Bound (B &B) is a systematic search algorithm to solve CSOP. B &B informally describes a backtracking application with an objective function (Apt, 2003). The objective function is used to maintain the 'Bound' value which is the best solution so far i.e. when a better solution over the bound value is founded; it is used to replace the current boundary. The successfully adopting B&B used to tackle constrained problems are indicated in (Backofen et al., 1999, Backofen, 2001, Yuanyuan et al., 2010, Wolf, 2009, Zanker et al., 2010, Jannach et al., 2009). The full discussion of using B&B in CSOP is covered in chapter 4 as it is a main search method adopted in this research.

Local Search

One big difference of the local search to the complete search is that the local search does not instantiate one variable at a time, but starts with a complete assignment to all the variables (Bartak et al., 2010). The general concept of applying the local search is to initialise a random solution, then steadily improve the solution iteratively until the final solutions are found (Hoos and Tsang, 2006). A number of local search methods have been proposed, and each of them has a unique method to improve the solution for certain problems (Hoos and Tsang, 2006).

Min conflicts Heuristics (MCH) instantiates all variables, and randomly chooses variables to assign values that minimise a number of conflicts. The min conflict algorithm has been applied to improving reusability in web service chains (Li, 2010).

Tabu search (TS) is a search that iteratively finds the answer. At each iteration, the current search candidate is compared to the current best solution, and keeps the better answer for the next evaluation. The unique characteristic of Tabu Search is a 'Tabu list' which functions to memorise the previously visits node to avoid the search being stuck in a local maxima. TS has been applied to sport scheduling problem as indicated in (Hamiez and HaoJ.K., 2001).

Guided Local Search (GLS) GLS is a penalty-based search. Its objective function consists of 2 components which are evaluation functions i.e. measuring the number of conflict and a penalty function to compute degrees of conflict, the weight of penalty is increased when the search has fallen below local maxima. GLS was investigated when solving the Travelling Salesman Problem in (Voudouris and Tsang, 1999).

Evolutionary algorithm (EA) is a class of algorithms that borrows an evolutionary principle, that a weaker population solution is incrementally replaced by a stronger one (Jones, 2008). Some of the important EA algorithms include Genetic Algorithms, Simulated Annealing, Ant Colony Optimisation and Particle Swarm Optimisation. It has been proved that solving constraint-based problems in mining classification rules (Chaochang and Hsu, 2005), the n-queen problem (Dirakkhunakon and Suansook, 2008), ship scheduling (Mertens et al., 2006), and the E-learning sequencing problem(de-Marcos et al., 2008), respectively.

2.4.4 CSP/CSOP Scheduling for real-life Application

One of the most popular applications of CP is scheduling. Scheduling is a problem involved in the allocation of resources to operate things over time. Applying CP to solve a scheduling problem can be categorised into 2 classes: CSP-based scheduling and CSOP-based scheduling. CSP-based scheduling concern has the main aim to allocate a number of limited resources to the processer i.e. human resources and facility resources, so that tasks can be processed without a conflict among processers for the resources, also satisfying a number of constraints to tasks. The schedule produced in this way is a feasible solution. Although it is likely that a number of schedules can be produced as solutions, any schedule can be used for the operation, as they are all considered to be equally good. In contrast, the CSOP scheduling is the CSP schedule that when considered the among the feasible schedules, there are solutions that are considered better than others i.e. using less resource are more economical, providing more satisfaction, etc.

Scheduling is a common problem, and CP is effective method in modelling real-life problems. Recently, a number of the constraints solvers have been introduced to assist Operation Researchers such that more attention can be devoted to modelling real-life constraint problems instead of 'reinventing the wheel' starting the research from the root of the problem i.e. CSP and CSOP. Some of the popular Constraint Solves are Choco, Ilog, ECLiPSe®, Gecode, Comet, CHIP, and Jsolver. Most of them are available for free download except, the Ilog which is the high end commercial solver by IBM. Table 2-6 indicates the current research using different solvers for modelling and solving the real-life scheduling problems.

Table 2- 6: Literature Review on CP Solving Scheduling Problems in Various Domains

Publications	Problems		Solvers						Scheduling Applications
	CSP	CSOP	choco	IlLog	Elippse	Mozart	Comet	Other	
(McDonald and Prosser, 2002)	/		/						Academic timetabling
(Zerola et al., 2009)	/		/						Data movement on Grid
(Garrido et al., 2008)	/		/						E-learning route planning
(Gregory, 2010)	/		/						Nurse rostering
(Hanset et al., 2010)	/		/						Operation theatre scheduling
(Tacadao, 2011)	/				/				Course timetabling
(Schaerf, 1999)	/				/				Sport tournament scheduling
(Edqvist, 2008)	/							/	Physician scheduling
(Kilborn, 2000)	/			/					Aircraft scheduling
(Chun, 1995)	/			/					Check-in counter scheduling
(Karali et al., 1996)	/			/					Crew scheduling
(Russell and Urban, 2006)	/			/					Sport scheduling
(McAloon et al., 1997)	/			/					Sport scheduling
(Bourdais et al., 2003)	/			/					Healthcare staff scheduling
(Shah, 2010)	/					/			Processer scheduling
(Wójcik, 2007)	/					/			Manufacturing scheduling
(Creemers et al., 1995)		/							Maintenance power network
(Malapert et al., 2011)		/	/						Batch processing
(Zerola et al., 2008)		/	/						Data movement on Grid
(Badr et al., 2010)		/	/						Building maintenance
(Zerola et al., 2010)		/	/						Multi-site data movement
(Girbea et al., 2011)		/	/						Production manufacturing
(Blomdahl et al., 2010)		/					/		Air traffic scheduling

Publications	Problems		Solvers						Scheduling Applications
	CSP	CSOP	choco	IlLog	Elippse	Mozart	Comet	Other	
(Schaus et al., 2009)		/					/		Balancing nurse workload
(Monette et al., 2009)		/					/		Just In Time Scheduling
(Reis and Oliveira, 1999)		/			/				Examination scheduling
(Abdennadher and Marte, 2000)		/			/				Course timetabling
(Ilhan and Bayram, 2006)		/			/				Teacher relocation
(Völker, 2008)		/						/	WSN resource scheduling
(Haıt and Artigues, 2009)		/		/					Production energy scheduling
(De Oliveira, 2001)		/		/					Train scheduling
(Tsao et al., 2009)		/		/					Airport scheduling
(Benini et al., 2008)		/		/					Computer processer scheduling
(Mouret, 2010)		/		/					Crude oil operation scheduling
(Artigues et al., 2010)		/		/					Production energy scheduling
(Boyle et al., 2011)		/		/					Ship maintenance scheduling
(Régin, 2001)		/		/					Sport scheduling
(Li et al., 2005)		/		/					Steal production scheduling
(Barra et al., 2007)		/		/					Transit network design
(Kovács et al., 2011)		/		/					Wind farm maintenance
(Ozfirat and Ozkarahan, 2010)		/		/					Fresh goods distribution
(Valouxis and Housos, 2003)		/		/					Course timetabling
(Váncza and Márkus, 2001)		/				/			Manufacturing planning
(Wai and Rebecca, 2007)								/	Crane lorry assignment

From the review, several observations can be made. Firstly, in real-life scheduling problems, the majority, required and included optimisations functions. However, in some particular applications, the same problem can be modelled with either CSP or CSOP depending on the business rules and justification of the researches. For example, the study of aircraft scheduling by Kilborn (2000) formulated the problem as CSP, but the study by Bromdahl et al. (2010) considered the problem as CSOP having the objective function of minimising the load cost and the delay cost. The CP scheduling application can be classified further by domains as depicted in Figure 2-15a.

Production: using CP for scheduling machines and resources in manufacturing processes

Transportation: mostly using CP for public transportation scheduling. Flight operations received the most attention (e.g. check-in counter, take-off & landing, crew scheduling), using CP for transport network design, also train scheduling. Road and private fleet operation are the study of

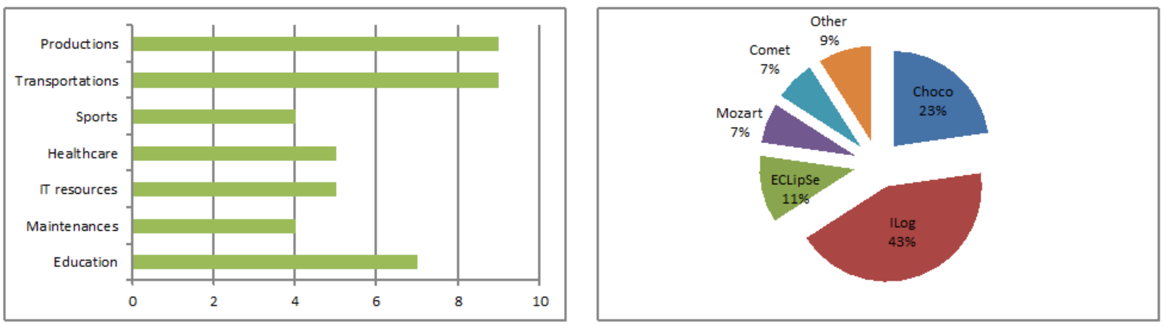
Sport: using CP for scheduling fixtures for sport in both round robin and home-away tournament for different kind of sports e.g. football and basketball

Healthcare: using for CP for scheduling or generating a working timetable for medical staffs

IT resource: using CP to schedule processor, managing networking traffic, and data transfer management

Maintenance: using CP for the maintenance of building, ship, wind farm, and power network

Education: using CP for course timetabling, examination, advisory service, relocation teacher, and E-learning content planning



a) CP by domain

b) CP by solver

Figure 2- 15: Current CP Literatures on Scheduling Application

From Figure 2-15b, it has been found ILog is the most popular CP solver, Choco, which is the second popular, was selected for this research regarding it is a non-commercial solver, but showing effectiveness in solving problems in several literatures. Also, the Choco operates for Java based programming language which is a familiar platform for the study. Other CP solvers that have been used including: ECLiPSe, Comet, Mozart, and other (e.g. Jsolver and CHIP).

2.5 Related Research

As mentioned previously in Figure 2-1, this research associates with 3 main areas and the background and the related research on each specific area has already been discussed in Sections 2.2, 2.3, 2.4. This section discuss the intersection between 2 or more research areas as shown in Figure 2-15 (it is developed as extension of Figure 2-1).

The interrelations can be discussed in terms of the overlaps between (among) 1) RFID technology and road fleet transportation (RFID-fleet) 2) RFID technology and Constraint Programming (RFID-CP) 3) Constraint Programming and road fleet transportation (CP-Fleet) and 4) RFID technology, Constraint programming, and road fleet transportation (RFID-CP-Fleet). The details of the related research of this research are discussed as followings:

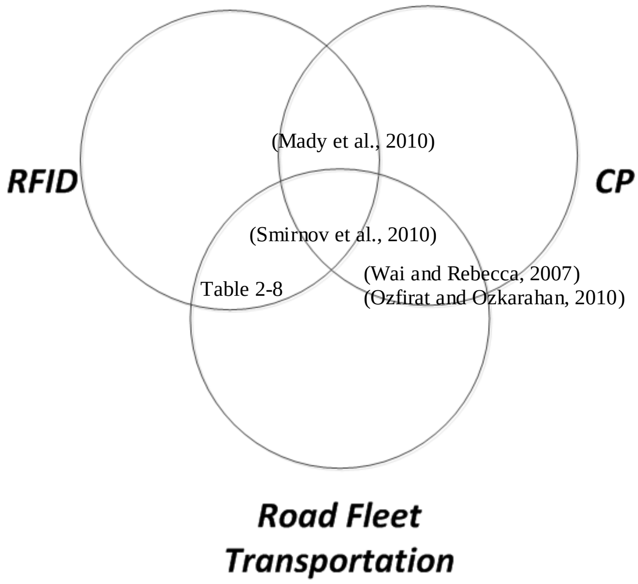


Figure 2- 16: Related Research

1) RFID-Fleet Transportation

A selection of the research of applying RFID technology for improving fleet transportation logistics operation is shown in Table 2-7.

Table 2- 7: Research Using RFID in Transportation

Papers	Types	Application	Key studies	Results/Founds
(Ustundag and Cevikcan, 2008)	'What if' analysis	Routing problem for waste bin collection	-Investigate optimal strategy for waste bin collection - mTSP problem -Conducting ANOVA to determine whether the increase of waste quantity of each zone the bin located has an impact on total cost	Bin location and their contained weight impact the cost of operation
(Zhang et al., 2009)	System development	Monitoring cold food transportation	-Developing the RFID-based temperature traceability management system of chilled and frozen food transportation	Testing indicated successful, the significant advantage is improving the automation of the system ,
(Wen, 2010)	Prototyping	Traffic management	-Proposing framework for the intelligent traffic management expert system - Attaching RFID tag to vehicle to enable vehicle to be audited , and check for criminal offences - calculate vehicle speed to identify average traffic speed in each road	Experiments were set up to check feasibility using RFID to track vehicles, it was found 1) maximum operating distance is 11.7 meter 2) identification speed achieve up to 68 km/h
(Rizzo et al., 2011)	System development	Container security	Developing a robust container security using combination of RFID active and passive technologies	-The key features of the developed system are: able to check the container are proper sealed, recording every operations made on the seal with time and date, remotely control the seal ; mean of the operating distance is 21.9 meter
(Ngai et al., 2012)	Prototype and survey	context-aware for fleet management system	-Develop a prototype Context-Aware for fleet management to detect un-expecting events causing of late delivery -RFID and GPS are used to provide vehicle context information -Evaluations were made with potential the user and the experts using a questionnaire	- Potential user rated each of the 11 index with mean scores indicate 3.5 to 4.15, and the expert rates 3.70 to 4.4 out of 5.00

In the past 5 years (2008-2012), RFID technologies have been applied to transportation applications. In 2008, Ustundag and Cevikcan (2008) studied the waste bin collection problem. RFID tags are mounted to the bins to gather bin locations to be the inputs for the model formulated as a multiple Traveling Salesman Problem (mTSP). The defined mTSP model was then solved by a commercial optimization software, and using the statistics method, ANOVA, the results and answer to be 'what if' question were analysed. In 2009, Zhang et.al (2009) researched the improvement of chilled and frozen food transportation using RFID, and it found the developed method was effective and able to improve the automation of cold product monitoring. Another observation detected after running the system on the case study found the large effect on temperature increase from opening the container door.

Wen (2010), in 2010, proposed the intelligent traffic management expert system. By attaching RFID tags to vehicles and storing related information, vehicles are able to be audited for criminal offences i.e. car theft, unpaid tax and toll tickets when integrated with the Rule Base System. Also average vehicle speed can be known, so traffic information of each road can be reported. The study conducted the experiment to evaluate the feasibility of the system. It was found that the maximum operating distance is 11.7 meters and 2) identification speed achieved up to 68 km/h. In 2011 Rizzo et al.(2011), focused their research on the security of commercial containers during transportation in which the combination of Active and LF-Passive are used. The developed system can: guarantee the containers are properly sealed; recording every operation made on the seal with time and date; and remotely control the seal with the operation distance up to 21.9 meters. And recently in 2012, Ngai et al. (2012) proposed a context aware decision support for handling accidents in logistics transportation. RFID was used to provide arrival and departure time, alongside the use of GPS to provide location information to detect accidents of a fleet. A conceptual prototype has been made, and surveys were used for validating the principle. The surveys from both potential users and experts indicated potentials and validities of the developed prototype.

2) RFID-CP

Examples of the literature on incorporating RFID technology to CP are also found. Specifically, RFID is used to capture real time input data, and send data to CP to generate a decision support.

Mady et al.(2010) proposed intelligent lighting control to enhance user comfort and energy saving. RFID was used for tracking the presence of persons to recognise the individual preference; the captured data was then passed to the constraint based optimisation model to adjust lamination based on the user preference at the same time using minimising energy. The variables in the model include blinding levels, the lux levels, and the external light. The simulation showed that energy can be saved approximately 42 %.

3) CP-Fleet

Wai and Rebecca (2007) developed the crane-lorry assignment system for a crane-lorry leasing company in Hong Kong. One of the business rule in the company is that subcontractors might be used when the owned assets are not adequate to serve customer requests. The developed system featured tailoring cranes and lorries to fit customer requirements to achieve certain optimal conditions. The research adopted the Jsolver as the constraint solver. The optimisation of the developed system were provided in 3 ways 1) minimising the use of subcontractors 2) maximising the 'size' of jobs i.e. selecting larger lorries first 3) maximising driver experience i.e. re-assigning drivers that were used to serve the same customers. The evaluation was made using 2 methods: 1) measuring a cost of outsourcing which was found that the developed system can improve the manual operation up to 4.71 % 2) measuring a quality of service-customers were more satisfied when an experienced was driver allocated. It was found that the satisfaction of customers, on the average, can be increased by 16%.

Ozfirat and Ozkarahan (2010) claimed their research novelty on modelling and solving Heterogeneous VRP (HVRP) with split delivery. The proposed algorithm has 2 phases. In the first phase the problem is clustered into subproblems and in the second phase, CP operated in ILog is applied to solve the subproblems. The developed algorithm was used to solve a fresh goods distribution problem of a retail store in Turkey, and the result indicated that the operation cost can be reduced by about 12 %. However, the main discussion of this research is in the focus of modelling and generalising a new class of VRP, not focused in the context of using CP to improve the operations of transportation logistics on its own.

4) RFID-CP-Fleet

The integration of RFID technology, Constraint Programming in a Road Fleet Transportation into the same framework similar to this research was studied by Smirnov et al.(2010). RFID played a role in identifying vehicles to audit for availability status. Identification data are used to incorporate an optimisation model to assign delivery jobs to a vehicle. In the optimisation module, apart from CP, 2 other optimisation techniques which are linear programming and the developed algorithm were also investigated. Eventually, the research adopted the developed algorithm in the system even though the solution was not optimal but, it can generate feasible solutions quickly. The system also incorporated with GPS, and Geographic Information System (GIS) to visualise and monitor the journey.

2.6 Novelty Adjustment

The literature review can lead to the inference of research novelty. There were existing researches studied on the common aspects of the research, but not exactly the same problem. The discussions on the research novelty are as follows:

A study by Sminov et al.(2010) is the most closely related study to this research in term of the research areas covered. The research conducted in this thesis and research by Sminov use RFID, CP, and fleet transportation. In fact they relate to those 3 components in the same ways i.e. using RFID technology to identify the vehicles, and then that information informs CP to generate a scheduling decision for logistics transportation. Also, both researches use Choco as the CP solver. However the study by Sminov et al. (2010), although it reported using CP in the research, the study eventually turned to use another method enabling to get a quick solution instead of getting the optimal solution. Alternatively, the character of the problem and the method of formulating the problem are different. Focusing consideration on the problem character, another research by Wai and Rebecca (2007) is more closely related to this research. The problem involved allocating vehicles to service customers of the company. There are 2 types of vehicles the company can locate: internal vehicles owned by the company and external vehicles which the company has to hire. The problem formulates as the constraint problem and CP was used to tackle the problem, but there are several different aspects remaining to this research described below.

What makes the present research unique from the existing research are 1) considering a fleet with groups of vehicles 2) constraints applied to both fleet and vehicle 3) the transportation time is multi period (split delivery) and 4) integrating RFID to support real time rescheduling.

2.7 Summary

Transportation is a critical activity in logistics management. In this research, road fleet transportation is the focus of this research, while the scope of the research problem is fleet scheduling for a class of problems where companies have to compose a fleet containing a number of internal heterogeneous vehicles, with the option of subcontractor's vehicles being available. However, the priority of assignment shall be given to assigning their owned fleet rather than hiring a fleet to optimise the asset utilisation. IT evidentially has the potential to improve the logistics process and is deployed to support 2 requirements: tracking and scheduling. RFID technology is a competitive technology among Auto-ID technologies as it has adequate storage memory, enable long distance identification, and able to identify objects simultaneously. RFID has been playing important roles in several application domains, particularly in logistics applications. Constraint Programming (CP) is another important component of this research. Several Operational Researches can be modelled as Constraint Satisfaction Problem (CSP), and Constraint Satisfaction Optimisation Problem (CSOP). CP is the method of solving those 2 problems. The outstanding advantage of the CP is to support modelling and solving real-life problems, instead of using mathematical methods to formulate a problem which usually requires a number of unrealistic assumptions to simplify the problems. In this research RFID and CP will be incorporated and applied in solving a road fleet transport logistics scheduling problem. The review indicates 1 publication (Smirnov et al., 2010) that discusses the domain covered in this research, but there are a large number of differences which can identify the uniqueness of this research.

Chapter 3

RFID for vehicle tracking

3.1 Introduction

The aim of this chapter is to discover and investigate the issues of deploying RFID Technology for vehicle tracking through the developed prototype and experimentation. Firstly, the discussion is on a technical background of the technology. Then the identification framework and implementation covering the hardware procurement and middleware developments are discussed. The experiments are set up to investigate the consequences of applying different configurations to RFID identification. The implementation results are presented and analysed, and finally a conclusion to the chapter is outlined.

3.2 Passive – Ultra High Frequency (UHF) RFID

A Passive-UHF RFID system is adopted in this research. The reason for selecting the passive system is mainly because of the practicality of the system. With no batteries required it gives the passive system remarkable advantages over other systems as they have a simple architecture, miniaturised size, low profile and having nearly zero maintenance cost (Dobkin, 2008, Hansen and Gillert, 2008). Ultra High Frequency is chosen due to its feature of long distance identification; see Chapter 2.3, which is suitable for vehicle identification.

3.2.1 Passive UHF Identification Processes

The general process of communication between a tag and a reader in a passive RFID system is: 1) a reader transmits a signal to power up the digital tag and that signal will also function as a carrier wave for communication (Beckner et al., 2009); 2) the reader modulates the data (i.e. RFID command) on top of a carrier wave, if a tag has been successfully energised and recognises a command transmitted from the reader, a tag will execute that command,

and return the result to the reader as shown in Figure 3-1.

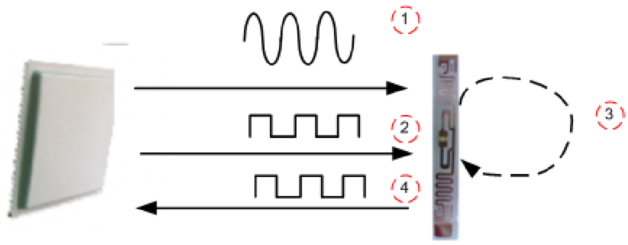


Figure 3- 1: Passive UHF Identification Process

3.2.2 Physics of Radio Frequency

Understanding the fundamental concept of antennae and behaviour of radio frequency can bring an optimum configuration of a RFID system. Several key terms that potentially affect the overall performance of RFID are discussed as follows.

In a Passive system, the tags harvest energy from the reader that they are communicating with and the process of procuring energy is referred to as ‘Coupling’ which can either be ‘Inductive’ or ’Radiative’ coupling. Unlike lower frequency systems like LF and HF which usually consume the energy in the ’Near Field’ region by using an inductive mechanism—antenna for LF/HF, the UHF the tag harvests the energy directly from the electromagnetic field generated around the antenna Reader receiving energy from the radiative mechanism from the ‘Far Field’ region. When the field reaches a distance of λ/2π (where the λ is the wavelength), it starts to separate from the antenna and propagate into space as an ’electromagnetic wave’ as depicted in Figure 3- 2. These waves act as an energy supplier and also a carrier wave for the tag to ‘backscatter’ the signal back to the Reader (Dobkin, 2008, Roussos, 2008, Banks et al., 2007).

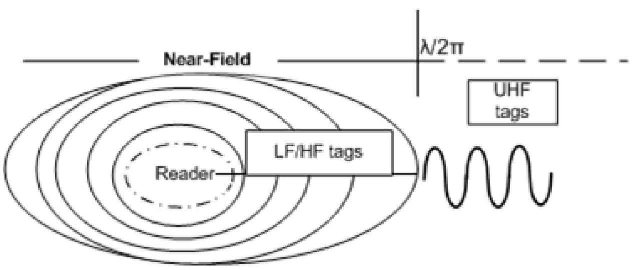


Figure 3- 2: Near Field vs. Far Field

When the Reader communicates with a Tag via the antenna, both of them must be tuned synchronously to gain the ‘resonant frequency’ (Sweeney, 2005, Muehlmann et al., 2009). This reflects the physics, such as shape and size, of the tag. For example, LF and HF tags are shaped like coils, which resonate better in the near field, and UHF tags have a flatter shape, which works better in the far field (Sweeney, 2005). RFID tags employ far field carry antennas that are usually manufactured as straight lines or dipoles, and the most basic type of far-field antenna is the ‘half-wavelength dipole antenna’, which consists of two components, each a quarter of the wavelength of the resonant frequency. For instance, a half-wavelength dipole antenna for Gen2 tags operating in the 915 MHz band would require each dipole to be 8.2 centimetres long (1/4 of the 32.8 centimetre wavelength) (Roussos, 2008).

The operating area of identification is determined by the ‘radiation pattern’ produced from the antenna and there are two main types of antenna. The first one is the basic ‘isotropic’ antenna that ideally radiates signals in all directions (omni-direction). This type of antenna (all direction) is rarely practically used in practise (the only case where it might be applicable is the scenario where the tags are in a circular layout. The second type of antenna is a ‘directional antenna’ which radiates signals only in a specific direction (Banks et al., 2007). Hence, the more antennas can be tuned to have a ‘direction’ property, the stronger the signal that can be fully utilised. The concept of two radiation patterns is shown in Figure 3-3.

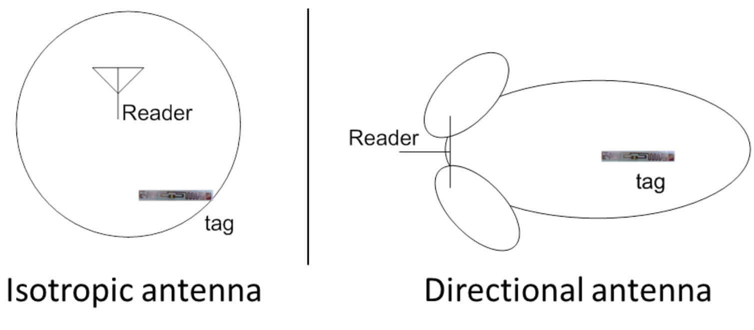


Figure 3- 3: Isotropic Antenna vs. Direction Antenna

Here the directional issue of RFID is related to the term ’polarisation’. Polarisation defines the manner of electromagnetic radiation which is ‘linear’ or ‘circular’ polarisation. In a linear antenna, Radio Frequency (RF) energy radiates from an antenna in a linear pattern, with either horizontal or vertical orientation. The circular antenna, as the name suggests, radiate

RF energy from the antenna in a circular pattern (Beckner et al., 2009). For the most efficient communication between a tag and a reader, the polarization of the tag antenna and the reader antenna needs to be the same (Sweeney, 2005). In addition, the identification performance also depends on the alignment of the tag and reader antennas, and the communication will completely fail if the tags are placed perpendicular to the reader antenna (when the angle of orientations is < 90 degrees) (Roussos, 2008).

Others factors that affect RFID performance include data modulation and encoding. Data modulation is the procedure involved in changing a carrier wave to a transmission medium which can possibly be Amplitude-Shift Keying (ASK); Frequency Shift Keying (FSK); or Phase-Shift Keying (PSK). Each technique has advantages and disadvantages regarding the transmission rate and noise immunity (Banks et al., 2007). For example, ASK can provide a high data rate but has low noise immunity where FSK has strong noise immunity but produces lower data rates, and PSK allows for relatively good noise immunity, and has a faster data rate than FSK. There are several data encoding algorithms that have been defined including Non-Return to Zero (NRZ), Manchester, FM0 encoding, Pulse-Interval Encoding (PIE) etc. The choice of algorithms affects the implementation cost, data error recovery and data synchronization capability (Banks et al., 2007).

3.3 Identification Framework and Implementation

The identification framework for vehicle tracking is shown in Figure 3-4 which simulates the vehicle in a depot environment. A passive UHF system is deployed by attaching tags to the vehicles and the antenna is mounted on the ‘gate’ the vehicle will pass through, together with the middleware to control the system. The data communication between the reader and middleware is made using the TCP/IP internet protocol. The data received by the reader is sent to the database to generate information for monitoring, decision making and other uses.

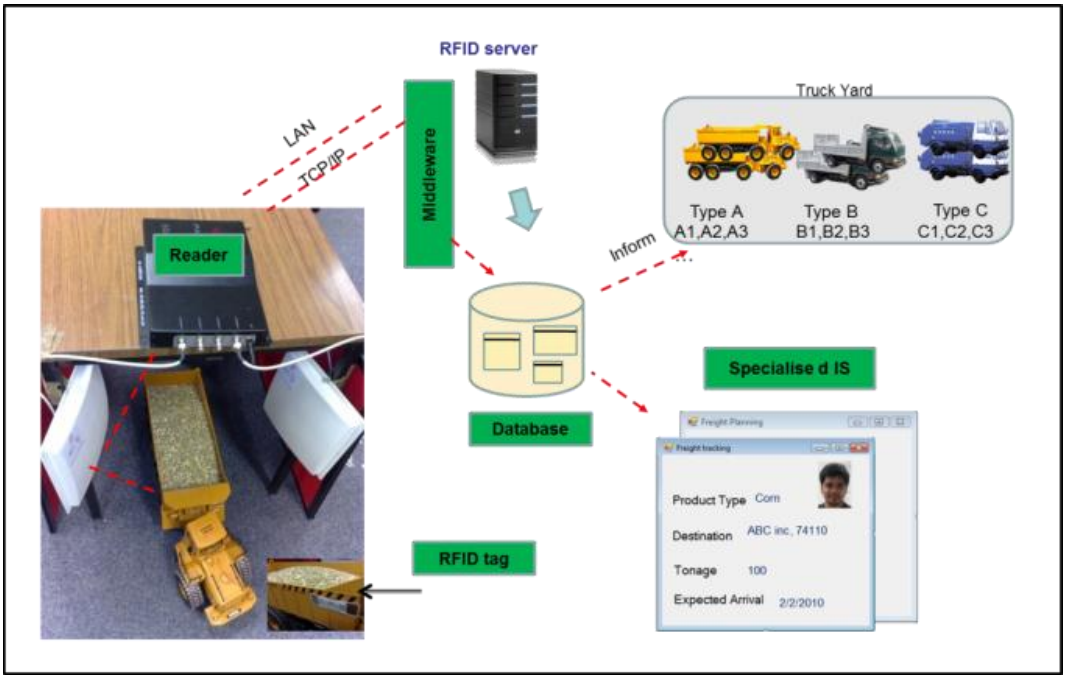


Figure 3- 4: Conceptual Outline of the Developed Prototype in the Lab Environment for Vehicle Tracking Applications

3.3.1 Hardware Procurement

One of the challenging issues of RFID deployment is how to procure a suitable hardware system, and the essential aspect is to have the 'right' equipment for the 'correct' application. The basic concepts of RF and antenna principles have been discussed in Chapter 3.1.2 regarding the system performance and constraints. Hardware vendors usually also implement the optimum physical design to the devices in term of different appearances and specifications of each device. There are several tag designs available from the manufactures (as outlined in Figure 3-5) and they vary depending on the applications regarding the copper pattern design.

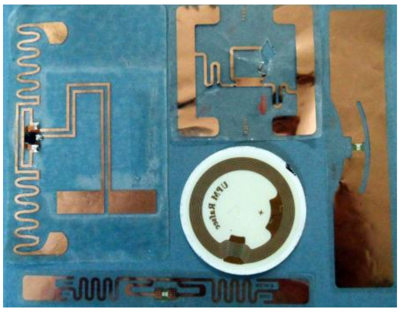


Figure 3- 5: Different Copper Pattern of UHF Tags

In the case of tag designs there are two significant aspects. Firstly in order to complete interrogation in a passive system the electrical current emitted from the RFID reader needs to hit the tag antenna orthogonally and consequently the impact angle from the reader to the tag is affected by the tag design. Secondly, the different patterns affect the amount of RF the tag can harvest with the intention of increasing the success rate of identification of the tag. Therefore, a tag contained many turns and wings shooting off the centre can be used to increase the chance of successful identification for the application that orientation of identification is unknown. While the precise straight pattern, applying a straighter tag is better off for the application that the orientation of identification is predictable as the tag contains a larger conducting plane which can harvest energy better (Sweeney, 2005).

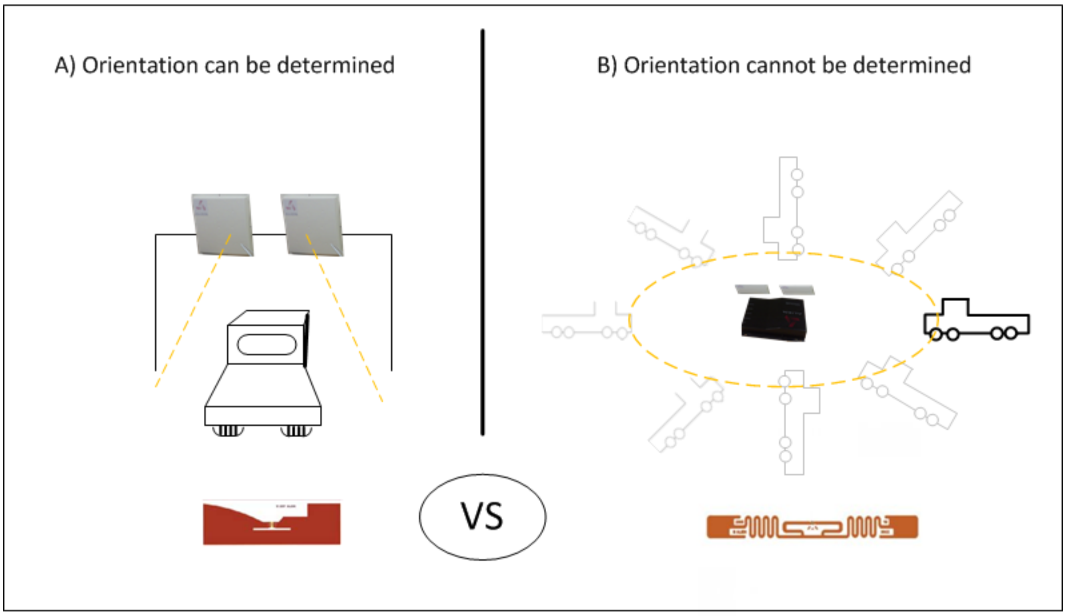


Figure 3- 6: Suitability of Tags for Different Applications

Figure 3-6 indicates tag designs that provide optimal identification for two vehicle tracking scenarios. Figure 3-6A) demonstrates a tag that is suitable for a fixed traffic system where orientation of identification can be definitely determined e.g. 1-way traffic, however Figure 3.6B) indicates a tag that shall provide better performance for a system that traffic orientation is undermined.

Some RFID vendors offer special features with their systems, for example, some systems may allow a user to retrieve certain special parameters, such as signal strength and/or velocity, from the system, other vendors provide flexibility in the Application Programming Interface (API) to develop a middleware and may offer Java API, C# API, or VB.net API, and some may offer multiple middleware APIs.

In addition, there is different legislation for using UHF frequency for communication, and each country permits a different frequency range to be used, so procuring hardware from overseas needs consideration of including this issue as an important factor. Permitted frequencies for several countries are shown in Table 3-1.

Table 3- 1: Permitted Frequency

Countries	UHF Frequencies
USA	902-928 MHz
Australia	918-926 MHz
Europe & U.K	865-868MHz
Japan	950-956 MHz
Thailand	920-925 MHz

Sources: Compiled from (Hansen and Gillert, 2008, Bridelall and Hande, 2010)

3.3.2 Middleware Development

As mentioned previously in Chapter 2.3 the basic function of middleware is to control all identification tasks of the system by using commands to direct a reader as illustrated in Figure 3-7. The typical functions of each RFID system include building up communications with the system(connect), reading a tag, and writing a tag, however, middleware is often required to host a special function to process data for each application. Apart from the requirement of basic functions to control the system, it was found that there were special requirements to develop two extra functions to overcome a default configuration of RFID for the vehicle identification including 1) handling stream data and 2) direction determination as additional features and outlined as follow:

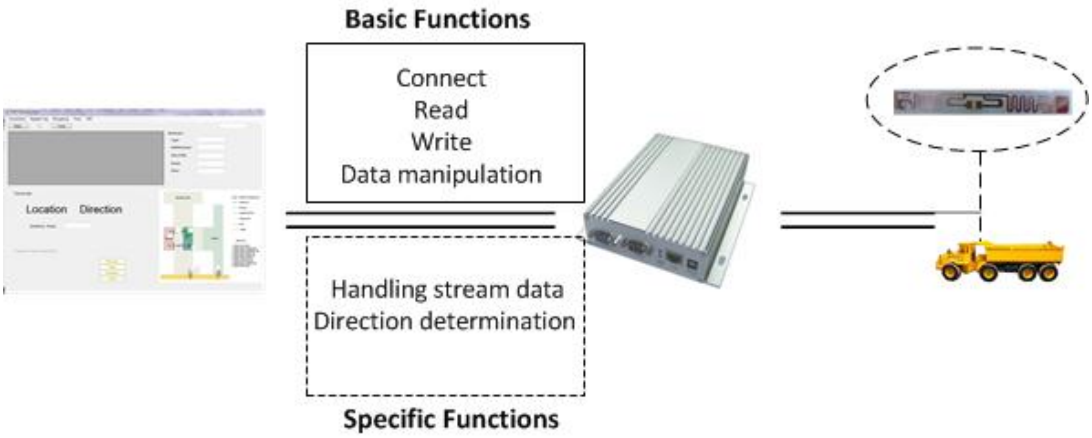


Figure 3- 7: Middleware Functions of RFID System

1) Handling stream data: Within the operating range of a typical RFID system the reader and tags repeatedly communicate with each other. In some situations, the RFID application has a prerequisite to manipulate a stream of data before identification. For example, in transport logistics, middleware might be required to investigate the first discovered time of a truck, so that a new assignment can be made to the driver and truck in the First Come First Serve (FCFS) principle. Also, in a racing car application, RFID might be required to determine the very first time that this car passed the finishing line. The example scenario using the logistic truck is shown in Figure 3-8.

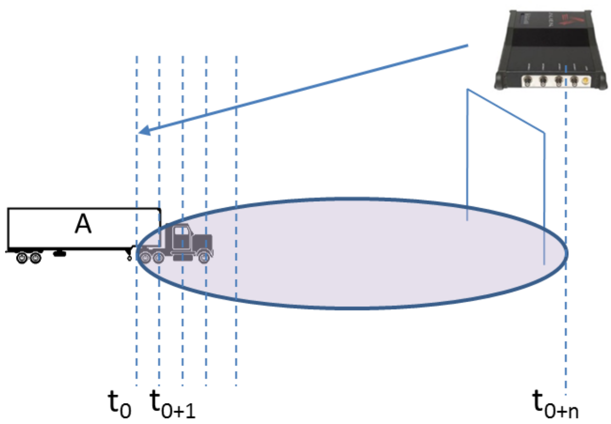


Figure 3- 8: Continuous Identification of Vehicle in the Operating Range

Figure 3-8 shows that, by only applying a default configuration of the RFID system, truck A with the tags will be firstly identified by the reader at a time t_o. Since the truck is moving and approaching the maximum operating range, it will be regularly identified at t_1, t_2, t_3, until it exceeds the operating range at t_{o+n}. The tracking data of the truck e.g. from discovery time will replace the previous identification data. Consequently, interpretation of the default configurations will not be able to indicate the time-stamp of the first identification rather it will only give the 'current time' of identification. Also, applying a straightforward solution by storing every identified data to a database to verify the first identification is not practical as the database will grow massively. An appropriate function of middleware is then required to handle RFID data stream of vehicle tracking application.

```
Tag List=[]

loop1:
        retrieving tags
        tag_i = retrieved tag
        check tag_i in Tag List

            if tag_i Not in Tag List
              add tag_i to Tag List  ---->
            end if

        add tag to DB
end
```

```
loop2:
    tag_i <- Timer_i
    Timer_i = Timer_i -1

        if Timer_i = 0
          remove tag_i
        end if
end
```

Figure 3- 9: Filtering algorithms of middleware

The algorithm is started by initiating the Tag List to store the identified tag. Loop1 indicates a cycle of identification where a reader is searching tag in an operating area. After tag $_i$ is retrieved, it is checked that the tag is already identified and stored in the Tag list. If not the tag is stored to the Tag List, and subsequently adding that tag to the database. Simultaneously, when tag $_i$ is added to Tag List, Timer $_i$ is also granted in Loop2. A Timer $_i$ is counted down to zero to remove the tag from the tag List. The concept of handling the data stream and limiting the time span of an identified data item is significantly required for a middleware for a practical application, as Mo et al.(2009b) proposed the notion 'time–to-live (TTL)' to describe the length of time identified data can live in a system similar to the using of Timer to handle data in Tag List in this research.

2) Direction determination: Another function that might be necessary for the vehicle tracking application is the direction determination as shown in Figure 3-10. The obvious requirement of the application is that one RFID reader is used to identify the direction of the moving vehicle and to convey the information for decision making. In this case middleware has to host the direction of the vehicle. Figure 8 demonstrates that using the default configuration as shown in the diagram the system can only recognise that both vehicles are located in the same area as identified by the reader. Therefore, it is the role of the middleware to use its possessing data to identify that A and B are positioned in opposite directions.

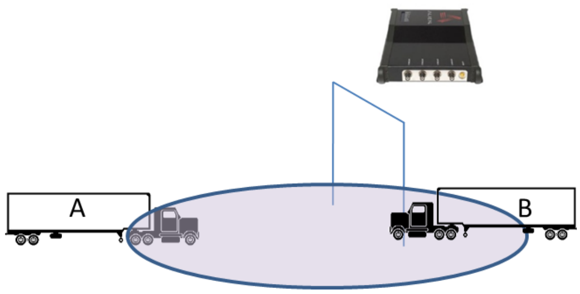


Figure 3- 10: Direction Determination Requirement

In order to implement the simple direction determination, it is proposed to use the rule - "an inverse of the last known orientation is the current orientation". To use this determination method, it is important to assure that a tag is identified only once in each vehicle journey (previous issue) i.e. vehicles will never be identified when they pass the operating areas. To cope with this, the middleware utilizes a timer to associate the data in a Found list. The span-time 't ' for each identification record is the amount of the estimated time that the vehicle shall take to travel the operating range of identification (t_{o+n}) as depicted in Figure 3-11.

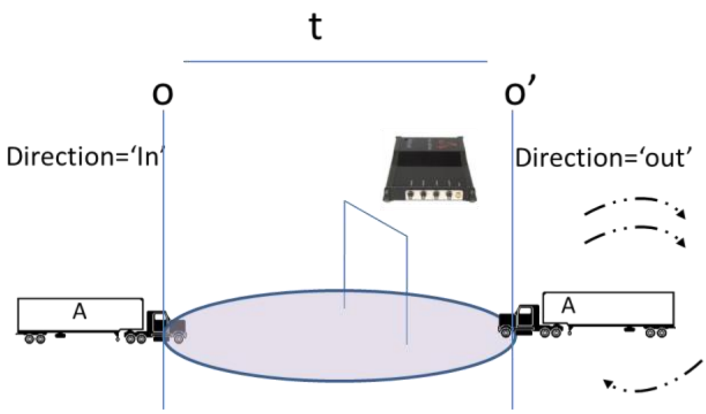


Figure 3- 11: Direction Determination

3.4 The Effect of Indoor Identification and Tag Positioning

When an RFID system is set up and configured for a real-life application, it is important to know the optimum conditions of the system in order to maximising its capabilities. In this research, the consequences of applying different configurations and working environments are observed through experiments. The experiment aims to measure two effects of the configuration: 1) the indoor effect, and 2) positioning of the attached tag.

To set up the experiment, the control parameters (the signal frequency, orientation and height of the reader, the position of the tags,) for the experiment are selected: 1) deploying the same Passive UHF Reader operated at 925 MHz; 2) the antenna reader is fixed at the gate to face the tag with certain angle(~45°); 3) the height of antenna from the ground level is 1.5 meters; 4) a passive tag was attached to miniature remote controlled vehicles at the same position. The middleware is developed to measure the success rate of readings at each condition. The frequency of interrogation is 1/s and set to run for 100 seconds for 5 replications and the screenshot of the middleware from the experiment is shown in Figure 3-12. The general interpretation is if the tag is identified 50 %, it means in 100 second (approximately 1.67 minutes), they are identified 50 times. In practice, vehicles can be in a cooperating area of the RFID for several minutes. For example, if a vehicle is located in an RFID coverage area for 3 minutes (equal to 180 seconds) and is picked up to 50% identification, it means a vehicle is identified 90 times which is overwhelmingly sufficient as the system requires identification only once.

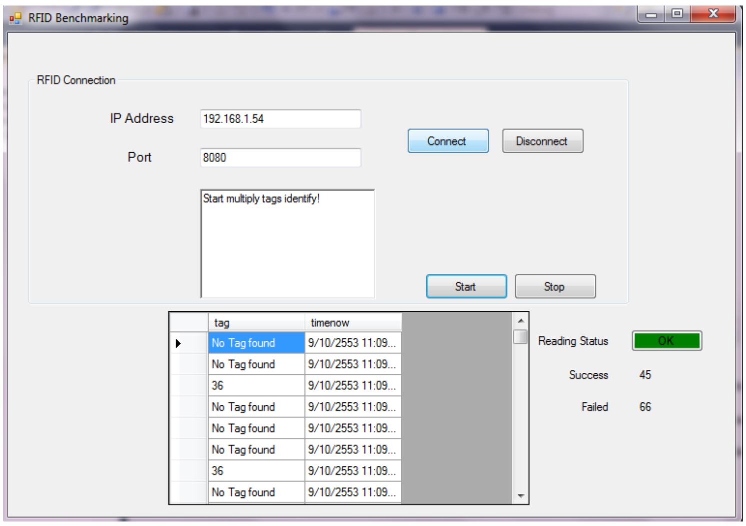


Figure 3- 12: Screenshot of Middleware Showing Result of the Experiment

Firstly, the effect of indoor identification is studied relating in a depot, where a vehicle is expected to be identified, as there is usually a covered area for shade e.g. a garage, silo, roof and/or tree canopy etc. The indoor operation was observed by running the experiment in two different environments: one is conducted in a corridor inside a building, and another is outside the building as shown in Figure 3-13. The experiment measures the readability of the tag where the tag is attached to the vehicle at a height of approximately 15 cm at 4 different horizontal distances at 1.5, 3.0, 4.5, 6.0 meters respectively.

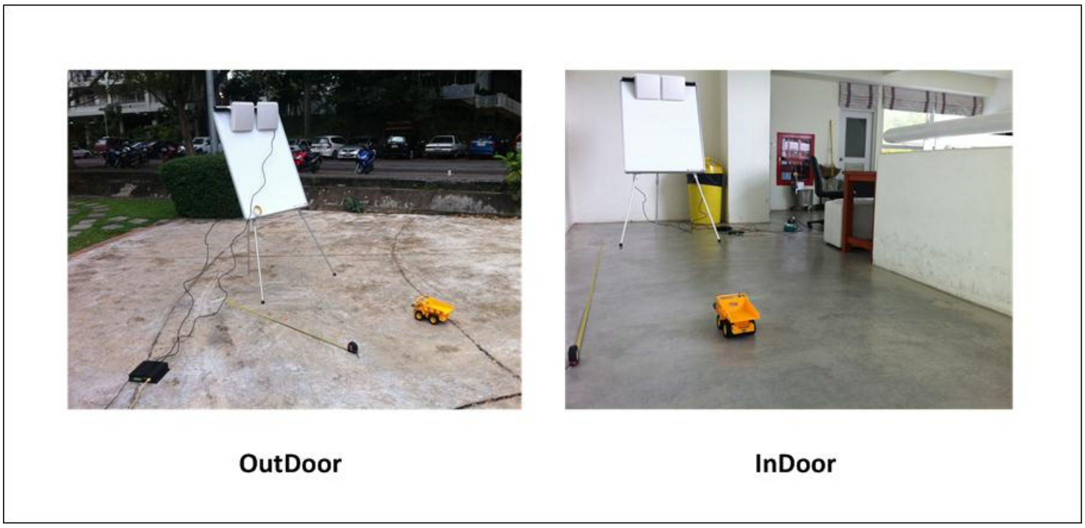


Figure 3- 13: Indoor vs. Outdoor environments

1) *Indoor effect:* Figure 3-14 shows the success identification rates of the indoor and outdoor identification at each distance from the reader.

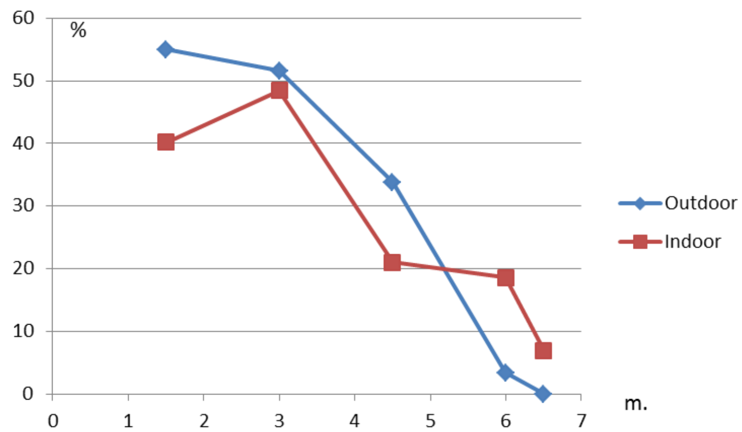


Figure 3- 14: Indoor and Outdoor's readabilities

In the outdoor environment, the average success rate at 1.5 meters is 55%, and it drops steadily to 51.6% at the distance of 3 meters. The success of the identification rate then drops sharply to 33.8% and 3.4% at 4.5 meters, and 6 meters, respectively.

In the indoor environment, the average successful identification rate at 1.5 meters is 40.2 %, and then it increases to 48.4 % at 3 meters. The success rates then fall dramatically to 21% at 4.5 meters and there was a further drop to 18.6% at 6 meters, then a 7% success rate at 6.5 meters.

Table 3- 2: Statistical Data from of the Indoor Experiment

Distances (m)	Outdoor		Indoor	
	X-bar (%)	SD	X-bar (%)	SD
1.5	55	3.03	40.2	0.75
3	51.6	4.50	48.4	4.84
4.5	33.8	2.36	21	4.15
6	3.4	1.20	18.6	4.59
6.5	0	0	7	2.10

Another significant finding from the experiments was the difference in Standard Deviation (SD) for the indoor and outdoor environment; it was found that except for the distance of 1.5 meters, the SD. at every measured points of the indoor environment is higher than the outdoor. This result implies that results of the indoor environment have a greater variety of chances that the tags will be identified and the statistics information is shown in Table 3-2.

The second experiment is conducted in an outdoor environment to investigate the effects of applying tags at different heights relating to its identification success rate. The configuration of this experiment is shown in Figure 3-15. There are 3 different heights of 4 different points measured in this experiment.

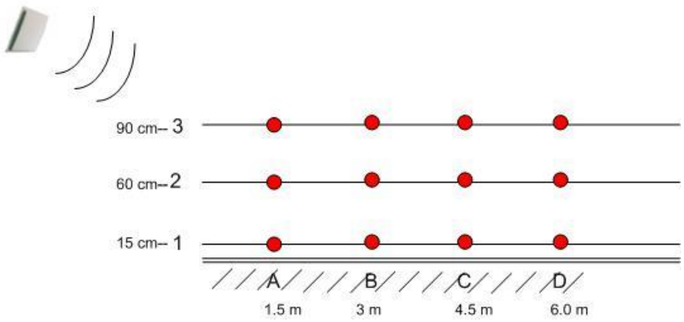


Figure 3- 15: Benchmarking Point of the Tag Positioning Experiment

The results show the height of the tag in outdoor environment affects the identification performance significantly. For example, if the tag is identified at 1.5 metres the optimal height is 60 centimetres, whereas the optimal height of the tag at 3 meters is 15 centimetres. The results for other positions are shown in Table 3-3.

Table 3- 3: Height vs. Readability

Distances	Average Read Success (%)		
	15cm	**60 cm**	**90m**
0.5	0	59.6	67
1.5	55	65.4	53.2
3.0	51.6	44	46.8
4.5	33.8	8	20
6.0	3.4	0	5

3.5 Discussion

In the hardware procurement phase, a simple standardised UHF RFID system for prototyping and experiments was used. The procured system supporting read/write operations complies with the RFID global standard (EPCglobal) and the reader provides 2 communication channels to the middleware system i.e. 1) TCP/IP protocol communication and 2) serial port (RS-232) communication respectively. The system generally provides satisfactory operability and is adequate for typical business usage. However, there is more sophisticated equipment available in tracking and also a higher number of antennas to be connected to the system. The increase in technologies tend to result in a higher price for the equipment for premiere service which may be financially justified in terms of Return On

Investment (ROI) for improving overall performance for a vehicle tracking system in some circumstances.

The implementations involved in a middleware development and experimental studies were conducted for the proof of concept and to investigate the feasibility of the method for a real-life application. However, the studies were conducted on a laboratory basis (small scale) as it would be difficult to use actual haulage trucks because of the financial costs.

In the process of middleware development, there were two specific issues resolved: 1) data streaming and 2) direction determination. The data streaming issue has been resolved successfully by using the data filtration algorithm. For the second issue relating to the direction determination, the rule – 'an inverse of the last known orientation is the current orientation' to provide a solution is applied. The advantages of this solution are simplicity of implementation, and the requirement for minimal and standard RFID hardware. This could contribute a simple solution for tackling the problem for mainstream users i.e. Small and Medium Enterprises (SMEs). However, this solution might have limitations in that it fits only the particular case where the initial state of the vehicle is pre-determined, and the maximum of the determined orientation is only 2 (e.g. left or right, or arrival or departure).

Alternatively, a more expensive method for direction determination might be applied by using the configuration shown in Figure 3-16. Two readers are used to identify a tag, if the sequence of identification on truck A is identified by X then Y, it means the truck is travelling from the left to the right and vice versa. Also, a similar but more economical solution was proposed in (Mo et al., 2009a) where applying 2 pair of antenna with 1 reader to detect a pattern of successful reading: at the both ends of the tracking area, the number of successful reading are low, and will reach a peak at the centre of a gate. However, the special features of the RFID reader or system extension are required to enable 4 input antennas and the system shall have to be able to distinguish which antenna reads a tag.

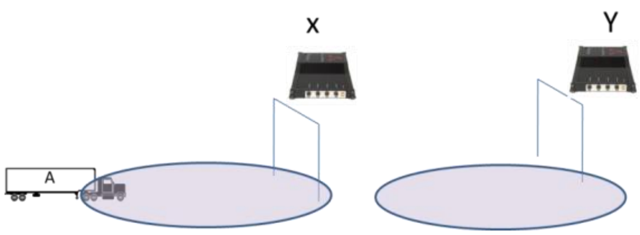


Figure 3- 16: Alternative solution for direction determination

The RFID system configuration issue using several experiments to obtain useful information is outlined. It can be seen that when RFID is used to identify objects, the identification is not always successful. For example, the highest percentage of read successes in all configurations is only 67% (height= 90 centimetres at distance=1.5 meters). However, vehicles are only required to be identified only once within an operating RFID coverage. For example, if a vehicle stays in the coverage area of RFID identification for 100 Seconds, it will require only 1 % of identification.

The literature indicates that an important cause that possibly leads to undesirable identification throughputs is the "multipath effect". The multipath effect is caused by the reflection of the radiated signal on the RF reflecting objects resulting in several radiated signals attempting to travel to the same tag, taking several routes, and those signals might cancel each other or amplify other signals (Rida et al., 2010). The severity of the effect depends on the object environment e.g. floors, roof, walls, etc. in the operating range (Hagl and Aslanidis, 2008) .

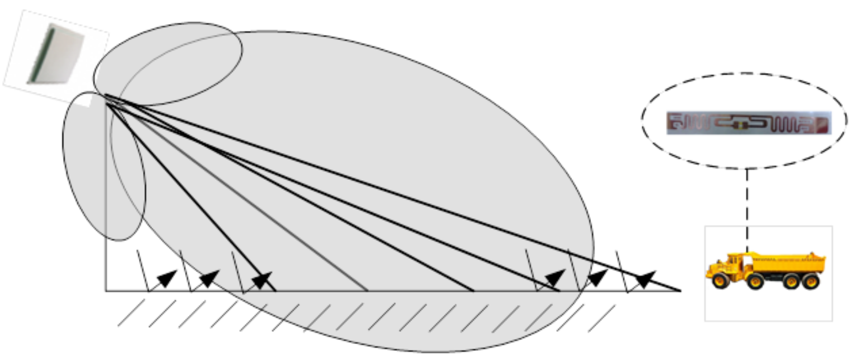


Figure 3- 17: Outdoor identification

The experiments in both indoor and outdoor environments unavoidably encounter the multipath effect. However, in the outdoor environment the effect is not as intense as the indoor environment. The tracking results in the outdoor environment produce a higher success rate of identification compared to the indoor environment because there is less interference caused by the multi-path effects and the only major source of reflectance is from the floor as shown in Figure 3-17. However, the identification rate reduces sharply over the distance as indicated in Figure 3-13.

The results from the indoor environment indicate more uncertainty of identification results as shown by the fluctuating relationship between the success rate of identification and distance. The measurement at each distance produces a greater standard deviation. This could imply that the intense effect of multipath is found, due to the system being comparable to the closed system where ceiling, floor, and wall are all high RF-reflecting materials as illustrated in Figure 3-18.

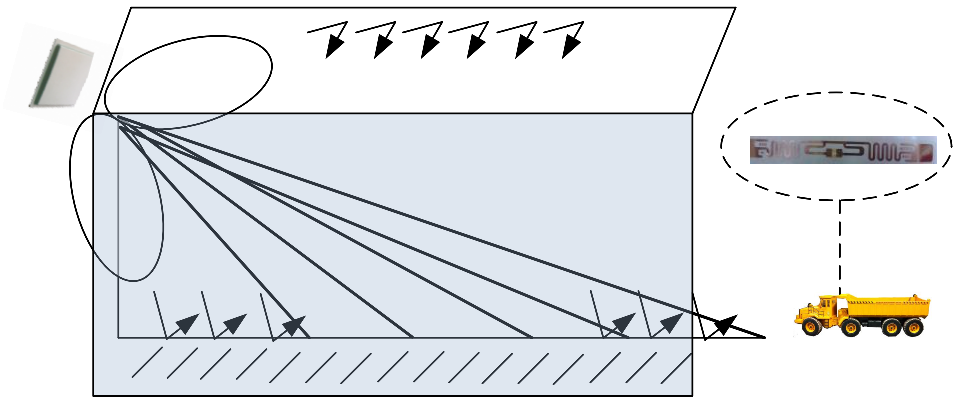


Figure 3- 18: Indoor Identification

Secondly, the results from the tag positioning experiment, shown in Table 3-3 indicate that the height of the tag impacts on the performance of identification significantly. It can be seen that at each distance of identification, when the tag is applied at the different heights, different percentages of successful identification are produced. One explanation is when the height of the tag changes, it also changes the impact angle of the radiated signal from the reader as shown in Figures 3-19 and 3-20.

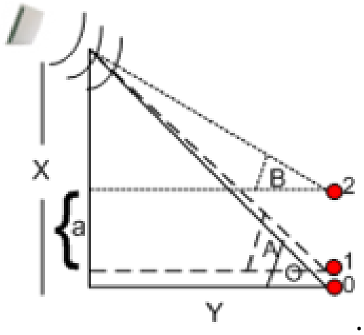


Figure 3- 19: Impact Angles for Different Height

The points 0, 1, 2 from Figure 18 represent 3 different heights of the tag position. Here X is the height of the installed reader, Y is the distance of the tag from the reader in x-axis, a is the height of the tag. To roughly calculate the impact angle between the tag and the reader is:

$$tan\theta = \frac{X - a}{Y}$$

The impact angle of each position is shown in Table 3-4 (the ground levels are reference levels).

Table 3- 4: Height and Impact Angles

Distances	Angle(Degree)			
	0 cm	**15 cm**	**60 cm**	**90 cm**
0.5	71.57	69.68	60.95	50.19
1.5	45	41.99	30.96	21.80
3	26.57	24.22	16.70	11.31
4.5	19.10	17.19	11.46	7.64
6	14.32	12.89	8.59	5.73

In a real-life application, when a tag is applied to a vehicle in different location heights e.g. bumper height, hood height, or roof height as shown in Figure 3-19, it will produce effects to the identification performance.

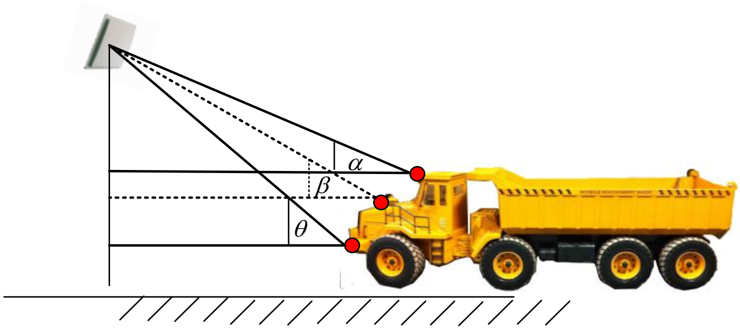


Figure 3- 20: Impact Angles vs. Tag Position

In the case where an application requires continuous, consistent, or very high precision identification, the system can contribute up to 100 % successful identification rate. A holistic solution can be applied to resolve the lower detection rate from the experiments. The system will unavoidably encounter both multi-path effect and different tag heights and this will influence the system performance. Applying several tags to a vehicle in different locations will improve the chance of identification for example, at each location for each interrogational time, of the vehicle being tracked. There should be at least one tag position that communicates with the reader successfully. If this does not occur the vehicle should not be authorised to pass the gate. As depicted in Figure 3-21, RFID can be synchronised with the access control device i.e. Ramp, to not allow vehicle pass through a gate unless it is identified by a reader.

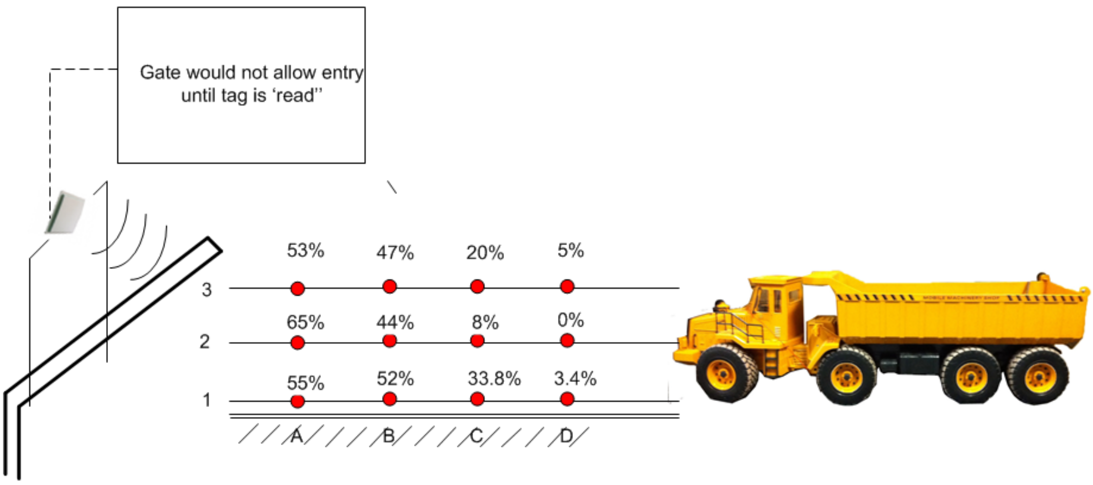


Figure 3- 21: Improving Performance by Attaching More Tags

3.6 Summary

This chapter investigated the practical issues of deploying the RFID technology for vehicle identification. It has researched several technical aspects of RFID implementation. The chapter investigated related theories behind RFID technology e.g. physics of radio frequencies, a hardware procurement to maximise throughput of the application e.g. choosing tag design and allowed frequency for global logistics. A prototype has been developed to demonstrate and identify challenges of applying RFID for vehicle identification in a real-life scenario. In the middleware development process, apart from a requirement of basic functions to control the system, it was found that there were special requirements to develop two extra two functions to overcome a default configuration of RFID for the vehicle identification including 1) handling stream data and 2) direction. The handling stream data is involved developing function to detect the first discovered time of identification and determining the vehicle direction is purposed to discriminate a direction of identification whether vehicle is dispatch or approach a depot. The experiments were set up to investigate and research different configurations and environments of RFID deployment. It has been found that the implemented system in an indoor environment produced fluctuating results at most distances. It has also been found that different height configuration of the tag produced scattered results for the same reader setup at each distance. Therefore, applying RFID to identify vehicles as a practical usage, a fine-tuning of hardware alignment is required to bring about the best performance of the system when operating in different working environment.

The study of deploying UHF-RFID technology for vehicle tracking in this chapter aims to investigate a using of RFID technology to collect reliable vehicle real time data, as this data will be used as the important input of the developed Decision Support System (DSS) in Chapter 4. The important issue in real-life applications is that a tag definitely requires identification before it can leave or enter premises (otherwise, it leads to the failure of intelligent decision support). The integration of the RFID technology and the developed decision support system on fleet scheduling will be discussed in the chapter 5.

Chapter 4

CP-based transport scheduling

4.1 Introduction

This chapter develops generic real time fleet scheduling for a split delivery with scarce resource constraints using Constraint Programming (CP) to solve a transport scheduling problem. The chapter covers a discussion of Constraint Programming principles, CP implementing Branch and Bound algorithm, CP for optimal fleet scheduling problem specification, problem representation, constraints and a modelling of scheduling problem. A proposed implementation method using Choco (Java-based Constraint Programming library) is outlined together with experiments and a discussion of a proposed application.

4.2 Solving a Scheduling Problem using CP

The first step in using CP for solving scheduling and other practical problems is to transform/ simplify real-life operational descriptions to formal CP representation. To start the discussion of this chapter, the model of the simple scheduling problem called 'Rostering' is formulated as an example model.

The problem definition is to find a weekly based schedule of employees for a supermarket running 3 shifts (Morning {M}: 08:00-13:00, Evening {E}: 13:00-18:00, and Night {N}: 18:00-23:00). There are $X_i \in X$ where i=1, 2, 3,…, n employees. The supermarket opening day is [Y_j] where j=1, 2,3,…6 denoted the day of week. If $S_{ij} \in S$ is a variable denoted an assignment of X_iY_j and S= {M, E, N}, allocating S_{ij} such that the following constraints are satisfied.

1) On each day employees should be allocated to each shift with cardinality [1, S]
2) In each day, each employee should be allocated to a shift type of at least one.

S_M, S_E, S_N denote the Morning shift, Evening shift and Night shift of Yj allocation having domain in a ranges of [Lb_M, Ub_M], [Lb_E, Ub_E], and [Lb_N, Ub_N], respectively. O_M^{xi} O_E^{xi} , O_N^{xi} denotes the number of occurrence of S assigned to employee X_i with a shift type of Morning, Evening, Night, respectively. O_M^{yj} , O_E^{yj} , O_N^{yj} denotes the number of occurrence of S assigned to day Y_j for a shift type of Morning, Evening, Night, respectively.

The constraints of this problem are:

1) $\forall S,\ Sij = 1$ (There is only 1 value for each coordinate)
2) $\forall\, Y,\ Lb_M^y \le O_M^y \le Ub_M^y$ (The number of employees allocated to Morning shift is satisfied)
3) $\forall\, Y,\ Lb_E^y \le O_E^y \le Ub_E^y$ (The number of employees allocated to Evening shift is satisfied)
4) $\forall\, Y,\ Lb_N^y \le O_N^y \le Ub_N^y$ (The number of employees allocated to Night shift is satisfied)
5) $\forall\, X,\ O_M^x \ge 1$ (Each employee is assigned to work for Morning shift at least once)
6) $\forall\, X,\ O_E^x \ge 1$ (Each employee is assigned to work for Evening shift at least once)
7) $\forall\, X,\ O_N^x \ge 1$ (Each employee is assigned to work for Night shift at least once)

The model (representation) of this rostering problem is shown in Figure4-1.

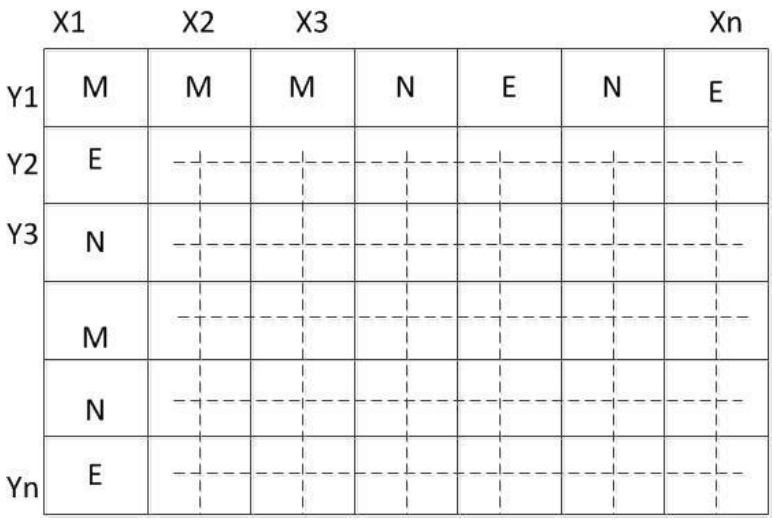


Figure 4- 1: CSP Modelling of Rostering Problem

After the CSP model is defined, the next stage is to solve the formulation represented by the model using constraint solvers. CP has been shown a successful approach in various applications, several constraint solver engines are developed as identified in Chapter 2.4.4 In this research Choco, which is a java-based library built on event-based propagation mechanism with backtracking structures is used (Jussien et al., 2008). Constraints in the system are handled through propagation mechanisms which allow the reduction of domains of variables and the pruning of the search tree. The propagation mechanism coupled with the backtracking scheme allows the search space to be explored in a complete manner (Malapert et al., 2009).

4.3 CP Implementing Branch and Bound Algorithm

Branch and Bound (B&B) is one of the successful methods for obtaining an optimal solution for solving NP-Hard problems (Korte and Vygen, 2008). It is a technique for simulating a complete enumeration of all possible solutions, without having to consider them one by one, by using a bound value to prune the search space (Bartak, 2008, Korte and Vygen, 2008). Principally, there are two key components in B&B as its name suggested. Branching is the process of partitioning a large problem into two or more sub-problems, and bounding is the process of calculating a lower bound on the optimal solution of a given sub-problem (Baker and Trietsch, 2009).

Applying B&B to a constraint problem, firstly constraint variables will formulate a constraint network in a Tree-like structure as indicated in Figure 4-2. Each tier of the network is represented by a constraint variable, where nodes represent the domain that belongs to a variable. A search is then conducted starting from the root node, then traversing a network depending which search method is implemented. For example, in Depth First Branch and Bound (DFBNB), the next node is 2.1 then 3.1, 4.1 and so on. The key advantage of BFBNB over a classical Breadth First Search (BFS) is that all nodes are not required to be instantiated as well as that their entire child nodes will not require investigation. A new ‘Branch’ (node) will not be instantiated further if its value cannot satisfy the ’Bound’ condition. For instance, if the problem involves solving a hard binary constraint problem as indicated in Figure 5, and suppose the constraint breaks at node 4.1, the node and its children (4.1, 5.1, and 5.2) will not be instantiated.

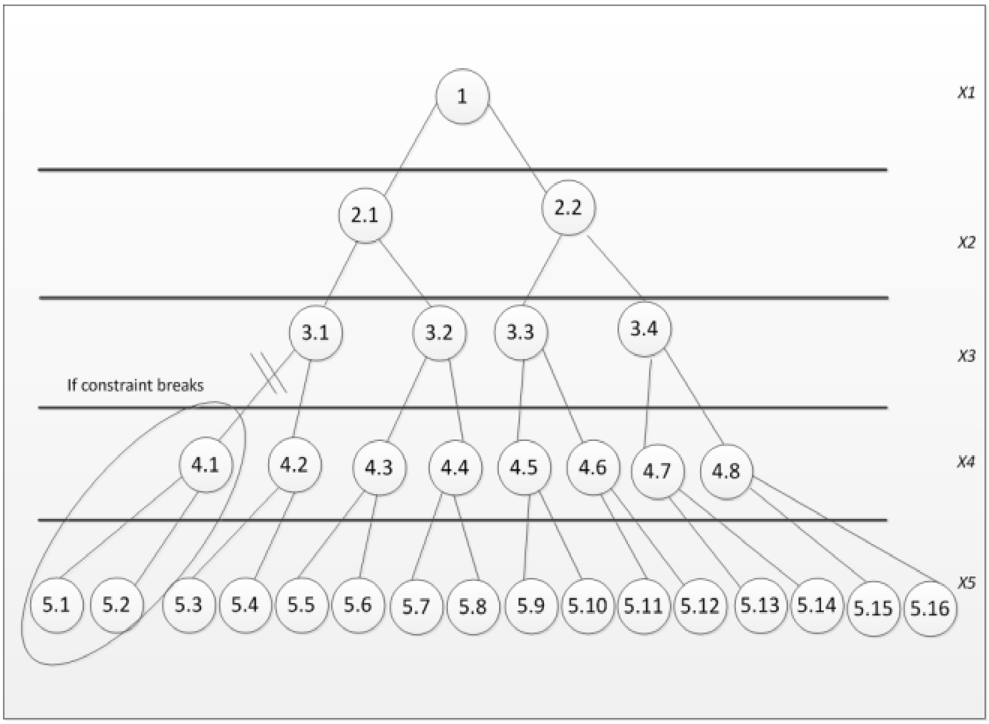


Figure 4- 2: Branch and Bound (B&B) Search in CP

When a B&B strategy is used for tackling a problem containing both hard and soft constraints, alternatively known as a Constraint Satisfaction Optimisation Problem (CSOP) as discussed in Chapter 2.4.2, a function is required for producing the Bound Value (BV) to decide that a node can expand further. In this scenario, not only will the node stop expansion when it cannot satisfy the defined hard constraints, but it will not expand further when BV is not ≥ BV of its parent (for a maximisation problem, and ≤ for a minimisation vice versa). The following example demonstrates using B&B to solve a problem (Tsang, 1993).

Given 5 variables, domains and constraint that they are associated, the problem properties are shown in Table 4-1.

Table 4- 1: Problem Properties

Variables	Domains	Constraints
x1	4,5	
x2	3,5	x2 ≠ x1
x3	3,5	x3=x2
x4	2,3	x4<x3
x5	1,3	x5 ≠ x4

The cost function is to maximise the assigned domain such that constraints defined in the 3rd column in Table 4-1 are satisfied.

Let Di denote a domain of Xi. The objective function is

$$\text{Max} \sum_{i=1}^{5} Di$$

If BV is initialized as 16 (Bvo=16), and sequentially it can be calculated from

Bf= ∑current assigned value + ∑ max unassigned value

Initially, the first variable to consider is X1. Since X1 does not associate with any hard constraints. Two possible domains (5 and 4) can be assigned to the variable and their BV are 21, 20 respectively. Regarding both nodes having BV ≥ BV_0, the node can be expanded and X2 is then investigated. With the value 5 the hard constraint X2 ≠ X1 is broken, the node cannot expand further (indicated by crossed node). The value 3, even though it satisfies the defined hard constraint, it cannot expand either as its BV is 19 which are < 21 (indicated by crossed shading node). The only node that can be expanded is X2=5.The complete process is shown in Figure 4-3.

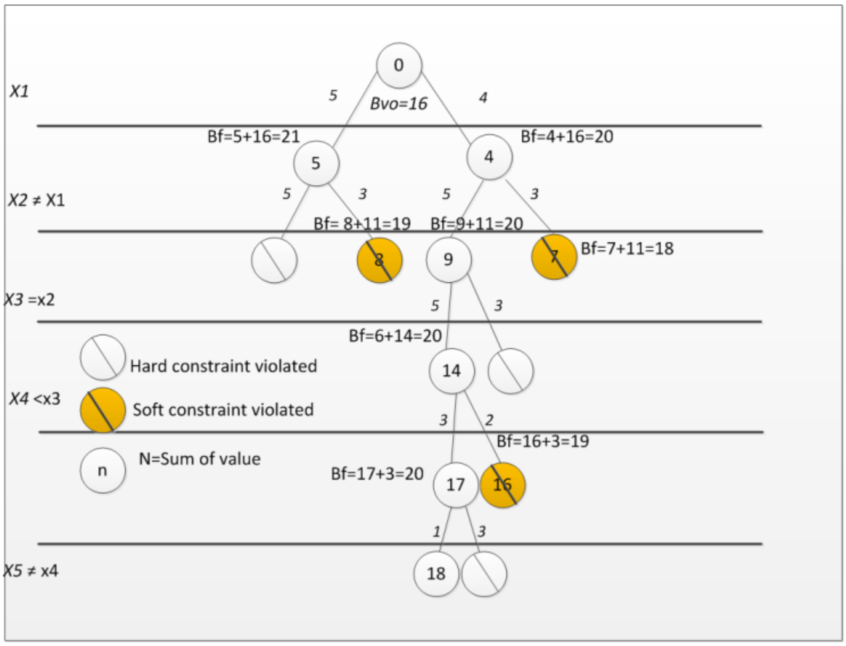


Figure 4- 3: B&B Search in CP for an Optimisation Problem

As Choco also utilises a B&B and backtracking approach to find a solution, several strategies are offered to shape a 'branching' of tree and ruling 'bounding' strategy for each search (Laburthe and Jussien, 2011). The built-in branching in Choco is outlined as Table 4-2.

Table 4- 2: Branching Strategies

#	Branching Strategies	Descriptions
1	AssignVar	A branching strategy allowed defines 1) a Variable Selector and 2) a Value Iterator and Selector. The Variable Selector is defined to prioritise the variable selection in the constraint network, and the Value Iterator and Selector are defined to sequentially investigate the domain of the selected variable.
2	DomOverWdegBranchingNew	An n-ary branching with built-in heuristic search where 3 variables are defined: dom is the current domain size, deg is the current number of un-instantiated constraints i, and w is the sum of the counters associated with the deg constraints. The branching strategy of this is to select the variable with the smallest ratio from $r = \min\left(\frac{\text{dom}}{\text{w x deg}}\right)$
3	DomOverWdegBinBranchingNew	A binary branching applied the same built-in heuristics search function in 2). The successive branch will never be assigned to the same value of its prior branches.

The Variable Selector is defined as a search parameter on how to sequentially select variables in the model. The Variable Selector is outlined as Table 4-3.

Table 4- 3: Variable Selectors

#	Variable selectors	Descriptions
A	MaxDomain	selects the integer variable with the largest domain
B	MaxRegret	selects the integer variable with the largest difference between the two smallest values in its domain
C	MaxValueDomain	selects the integer variable with the largest value in its domain
D	MinDomain	selects the integer variable with the smallest domain
E	MinValueDomain	selects the integer variable with the smallest value in its domain
F	MostConstrained	selects the integer variable involved in the largest number of constraints
G	StaticVarOrder	selects the integer variables in the order they appear

The parameter Value Iterators/Selectors defines the strategy of how variables initiated their value, or what rule applied when making an iteration. The Value Iterators/Selectors is defined as Table 4-4.

Table 4- 4: Value Iterators/Selectors

#	Value Iterators/Selectors	Description
I	DecreasingDomain	selects the integer variable with a largest value
II	IncreasingDomain	selects the integer variable with a smallest value
III	MaxVal	selects the largest value in the domain of the integer variable
IV	MidVal	selects the closest value (equal or greater) to the integer variable domain midpoint
V	MinVal	selects the smallest value in the domain of the integer variable:

The combination of Branching Strategies, Variable Selectors, and Value Iterators/Selectors are made to investigate the good search strategy in Chapter 4.4.1.

4.4 CP for Fleet Scheduling Problem

In solving optimisation scheduling problems, there are usually two parts to consider: 1) the objective aimed at achieving e.g. Minimisation f(x) or Maximisation f(x) and 2) the constraints to limit solutions. The common ultimate goal of every optimal scheduling problem is similar which is to improve operational efficiency. However, the fact that in reality no companies operate exactly alike – each has its own operational methods, and has to associate different constraints (Kilby and Shaw, 2006), also the efficiency can be interpreted in several definition. There are many possible ways to define the objectives and the constraints of the problem. For example, some typical objectives in a scheduling problem are: Minimising the global distance travelled, Minimisation of the global transportation cost, Minimisation of the number of vehicles (or drivers) required to serve all the customers, Balancing of the routes, for travel time and vehicle load, and Minimisation of the penalties associated with partial service of the customers, and the major factor affecting constraints include customer, vehicle and driver (Toth and Vigo, 2002). The focus of this research is to propose a scheduling method for the agricultural delivery of the case study in Thailand. The objective, constraints, problem specification, and problem representation are discussed below.

4.4.1 Problem Specification

The CP-based scheduling of this research is formulated from the real problem from a case study problem from Thailand (details of the case study are discussed in Chapter 5.1). In brief, the case study company is one of the largest wholesale grained-crop suppliers in northern Thailand. The company is required to takes approximately 1-3 days to deliver its product from depot-to-door to customers around Thailand. The company commitment with its customers is to complete each delivery order in a week. The Truck-Load delivery system (TL) is adopted which means that each truck will definitely serve only one customer, and the driver is responsible for the vehicle. Vehicles are heterogeneous by their capacities and model. The current operation is to complete the order; the fleet manager will compose a schedule of deliveries to meet the tonnage with the fleet available. If there are insufficient vehicles the company will hire subcontractors to join the fleet. However, using a subcontractor can increase the company operation cost and sequentially leading to a reducing of the profit margin significantly.

A summary of the problem's properties using the transport classification scheme (Panapinun and Charnsethikul, 2005) is shown in Table 4-5.

Table 4- 5: Problem Properties

#	Criteria	Description
1	Size of fleet	Multiple vehicles
2	Type of fleet	Heterogeneous
3	Housing of vehicle	Single depot
4	Nature of demand	Stochastic demand
5	Nature of product	Homogeneous
7	Objectives	Minimising the use of subcontractors

4.4.2 CP VS Classical Representation for a Vehicle Scheduling Problem

It can be inferred from the literature survey that the classical problem formulation for solving transport planning problems is a formulation of a Vehicle Routing Problem (VRP). The VRP formulation generally represents a problem using theoretical graph modelling. For example, a typical formulation is G= (V, A) where V is a vertex to represent a node of the customer, and Vo represents the depot, while A corresponds to an Arc between the vertex which could represent cost or distance between nodes (Toth and Vigo, 2002). The optimisation of VRP involves finding a node configuration that satisfies all constraints and achieves some certain optimal goal e.g. cheapest travelling. Although, there are several VRP variants developed to solve different transport problems, it appears that most of the formulation must be defined strictly under certain assumptions impeding the practicality of a real life situation. For example, the simplest form of VRP called the Travelling Salesman Problem (TSP), under a requirement that only 1 vehicle is allowed in the model and the vehicle also has unlimited capacity. In a case of solving a similar problem but having multiple vehicles, the TSP formulation must be extended to "multiple Travelling Salesman Problem

(MTSP). The concept could also be developed further to “Vehicle Routing Problem (VRP)” where a demand to enforce vehicles having limited capacity exists.

Currently, there are no exact VRP models defined for the problems outlined in this research despite various studies which have tried to tackle aspects of these issues. For example, a fleet composition problem has been defined under VRP consideration called the Fleet Size and Mix Vehicle Routing Problem (FSMVRP) or FSMVRPTW when Time Windows are imposed (Dell'Amico et al., 2007). However those formulations have two impractical assumptions, firstly, vehicles have infinite supply and secondly each customer can be visited only once. To allow customers to be visited by a vehicle more than once, the problem can be developed by a ‘split delivery vehicle routing problem (SDVRP)’ (Archetti et al., 2008). However, the SDVRP results in another limitation in which all vehicles in a system have to be homogeneous.

Instead of solving the outlined problem using the VRP formulation, it is proposed that an alternative method using the Constraint Programming (CP) method is used. To avoid extra complexity of the formulation a VRP formulation typically represents each unit in a model as an independent vehicle. CP constraints can be defined at every level of the problem including a fleet, which results in more logical constraints/rules to be considered. For example, a constraint can be used to enforce at the fleet level to avoid scheduling a static assignment i.e. each fleet always has the same members which might be prone to conspiracy i.e. fuel shrinkage. Also, this study focuses on the fleet tracking composition and assignment problem only. The routing is not an issue of this system as each vehicle makes a long-haul with a full truckload to one customer only.

4.4.3 Problem Representation

In preparing to solve this problem using CP, the concept is formulated as depicted in Figure 4-4. Order {O1, O2, ...,On} with a demand amount{A1, A2, ...,An} are made to the company. The company then composes fleet {f1, f2, …, fn} by allocating finite number of available owned vehicles {v1,v2,v3,…., vn} with a containing weight {w1,w2,…, wn}, however each vehicle has limited capacity {c1,c2,…, cn}.

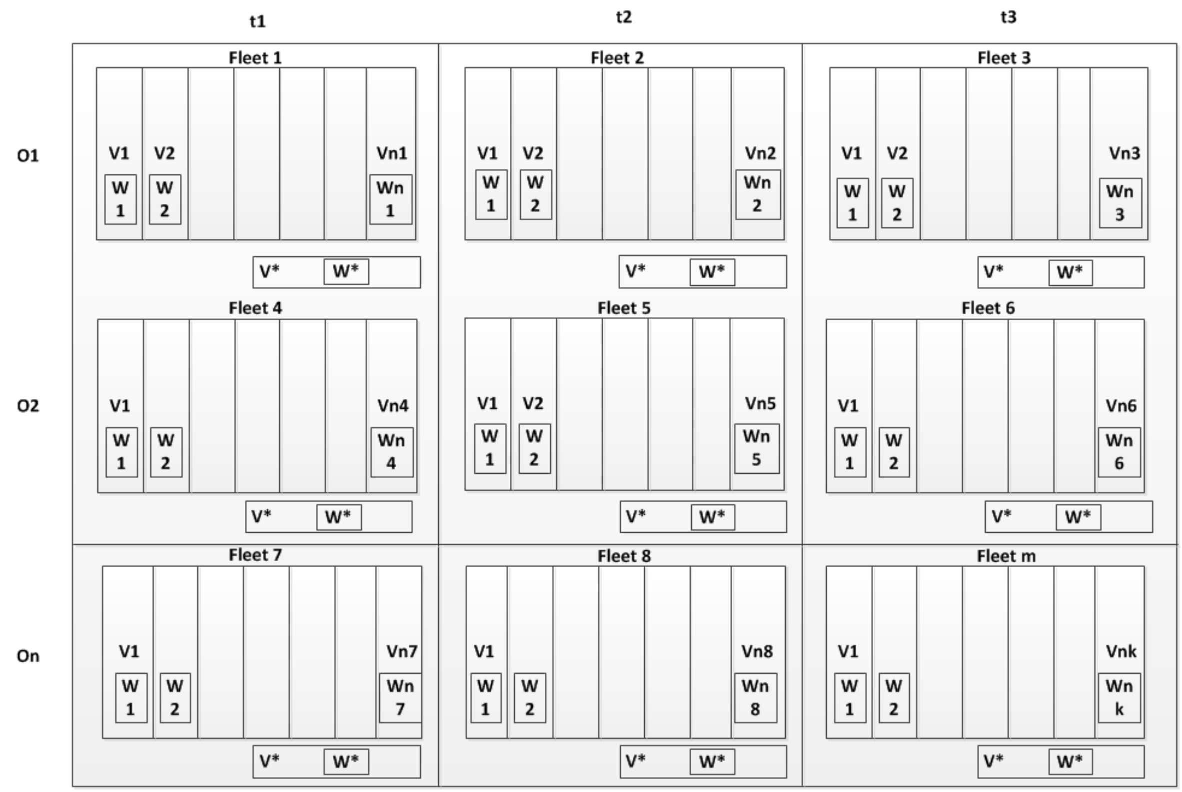


Figure 4- 4: Problem Representation

If the fleet (a summation of delivering weights) cannot achieve Ai, the extra load (W_i*) can be used from subcontractors. The objective is to assign tasks to the vehicles with the suggested weight for the current N order such that delivered weight of subcontractors is minimised, and satisfying all hard constraints defined by the formal formulation listed from 1) to 8) . It is noted that the hard constraint being listed under the following CSOP formulation has equal weighting and no sequence. If any of the defined constraints is not satisfied, it will be considered as an infeasible solution. In some other related problems, constraints might be required to have different weights and priorities and the problem would need other formulations such as a weighted constraint satisfaction optimisation problem (Rossi et al., 2008), or a multi-objective optimisation problem (Marler and Arora, 2004) which are outside of the scope of this research.

The objective is to minimise the utilisation of the subcontractors

$$\sum_{i=1}^{n} W_i *$$

and to satisfy the followings hard constraints.

1) Each vehicle can carry weight Wi, The lower bound is the lowest weight and the upper bound is the maximum capacity of the vehicle.

$$\mathrm{Wi} \in \{\mathrm{Wi}lb,\ \ldots.,\ \mathrm{Wi}ub\} \,|\, \mathrm{Wi} \subseteq \mathrm{W}$$

lb=lower bound, *ub*=upper bound

$\mathrm{W} = \{\mathrm{Integers}\ x \,|\, 0 \le x \le c\}$, where c is the maximum capacity of the vehicle.

2) Groups of vehicles are composed to make a fleet, and a feasible fleet only either has a total weight excess defined minimum weight, or equals zero

$$\mathrm{fi} < \mathrm{feasible} > \Leftrightarrow \sum_{i=1}^{n} \mathrm{Wi(fi)} \ge \mathrm{fmin} \cup \sum_{i=1}^{n} \mathrm{Wi(fi)} = 0, \forall \mathrm{fi} \in \mathrm{N}$$

3) Every order shall be served by at least 1 owned-vehicle fleet , and every order must be served

$$\forall \mathrm{O}, \mathrm{Sr[i]} > 0$$

4) Fleets are assigned to deliver goods for all current order. Supplement weight ($W*$) from subcontractors can also be used to compliment fleet capacity

$$\sum_{j=1}^{m} \left(\sum_{k=1}^{n} \mathrm{Wkj} \right) + \mathrm{W*} = \mathrm{Oi}, \quad \mathrm{i} \in \mathrm{N}$$

5) Once a vehicle vi is allocated for order Oi, Time Windows (TW) t∈TW is used to define a working period, none of the order can be reassigned to vi in TW. Also, to satisfy a safety regulation, time windows shall include a break time for the driver. When t = traveling time +unloading time + break time

$$\forall \mathrm{O}\ \&\ (\forall \mathrm{v}\ \mathrm{t} \in \mathrm{TW}), \mathrm{Wi} = 0$$

6) Sets of feasible fleets in the same schedule are not allowed to be equal (to prevent conspired cheating). When { v1,v2,v3,…} ∈ fi & { v1,v2,v3…}∈fj , i ≠ j

$$\forall \mathrm{f}, \exists \mathrm{vi} \in \mathrm{f}\ \text{such that}\ \mathrm{fi} \ne \mathrm{fj}$$

7) Some vehicles are not allowed to deliver particular orders; for example the customer premises may not be suitable for a truck and trailer combination

$$\exists Oi, wi = 0$$

8) The sum of weights delivered by owned vehicle and weighted delivered by subcontractor equal requested order

$$\sum_{i=1}^{N} Sr_{[i]} + \sum_{i=1}^{N} W *_{[i]} = Order[i]$$

Modelling the problem as a CSP, the problem size is vn × Dn × On where each of the components represents a number of vehicles, number of days in a schedule and the number of orders respectively. There are several variables with different domains involved to decide the feasibility of the problem. For example, to deliver a service for Order (i), given a minimum capacity (value for deliver) and a maximum capacity of each vehicle being 32 and 35 tons respectively; otherwise it delivers nothing (0 ton), minimum fleet size is 70 tons, and maximum fleet delivered by a subcontractor is 150 tons. Since the schedule is developed for a long-haul transportation application the number of days required for travelling in every journey is assumed to be equalled (i.e. every order requires the same amount of time e.g. 3 days for travelling).Variables and their domains for the problem are shown in Table 4-6.

Table 4- 6: Variable and Domain of the Problem

Variable	Meaning	Domain
W	Delivered weight by each vehicle	$\{0\} \cup \{32\} \cup \{35\}$
MinF	Minimum fleet size	[70,Order]
MaxH	Maximum fleet delivered by subcontractor	[0,150]
Foi	Decision Variable for fleet utilisation	[0,1]
Fv	Fleet value	$[0, \sum_{i=1}^{n} V_i]$
V	Decision Variable for vehicle utilisation	[0,1]
Max_order	Highest amount of the requested order	[0,∞]
Max_sub	Maximum load can be delivered by subcontractor	
Sr [i]	Sum of weight delivered by the owned vehicle for order i	[0, Max_order]
Extrar[i]	Sum of weight delivered by the owned vehicle for order i	[0, Max_sub]

4.4.4 CP Implementation

The formulated problem in Chapter 4.3.3 was implemented by the Choco-library with a Java programing implementation. Figure 4-5 illustrates the overview framework of the developed system. The system retrieves related data for the decision from two inputs: the database and user-defined parameters. For example, it retrieves current order information such as product type and order amount from the database and retrieves scheduling parameters such as number of days to be scheduled and fleet parameters from the user inputs. There are hard constraints, except the objective function which is a soft constraint of the system.

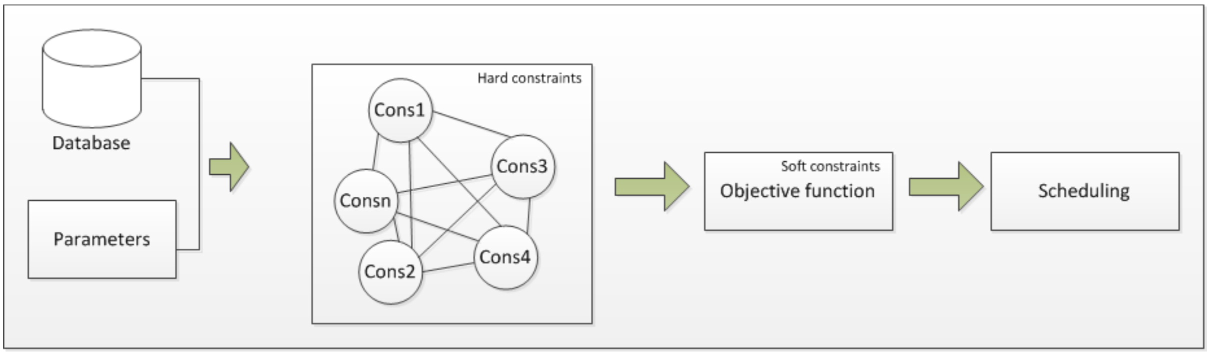


Figure 4- 5: The Proposed Framework

To tackle the hard constraints using Choco, a constraint network is formulated, where each constraint has a number of variables. Any domains of the variable that do not satisfy the defined constraint will be removed. If there is at least one domain of the variables existing, a feasible solution can be found; otherwise, the problem has no solution or can be called an infeasible problem. When a problem has a set of feasible solutions, an optimal solution (among those feasible solutions) is then investigated further. The constraints defined previously are mainly involving three areas: vehicle, fleet, and order. Each of them interacts with each other to formulate a hard constraint network. The primary principle of CP implementation is to use a propagation mechanism to adjust the domain of each variable in the network such that the domains of the variables do not violate other variables that they are associated with. From Figure 4-6, the constraints 1, 5, 7 are defined to control the assignments of vehicles, the constraints 2 and 6 are mainly related to fleet assignments, the constraints 3 and 4 are overlapping between the fleet and order, and the constraint 8 is involved the assignment of the order. The ultimate goal of this CP implementation is to take the feasible domain from the hard constraint network solving the subcontractor minimisation problem further which is defined as the objective of the problem. Also the objective function is closely tied with the hard constraint 4.

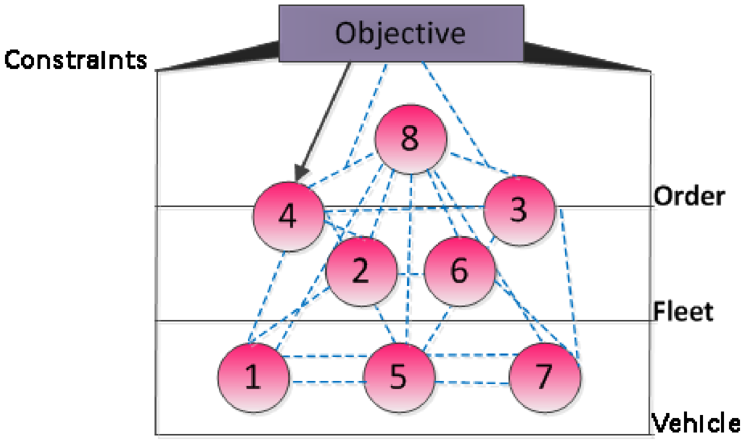


Figure 4- 6: The Constraint Network of the Problem

To tackle the hard constraints in a constraint network, some constraints require individual sub-algorithms and associating with variables and other constraints. The following indicate those sub-algorithms for the constraints 1, 2, 5, 6, and 7. The sub-algorithms for tackling the stated hard constraints are Algorithm 1 for constraint 5 (Figure 4-7a), Algorithm 2 for constraint 6 (Figure 4-7b), Algorithm 3 for constraint 1 and constraint 7 (Figure 4-7c) and Algorithm 4 for constraint 2 (Figure 4-7d), respectively.

ALGORITHM 1—CONSTRAINT 5

```
for any fj,fk ∈ F in tw, tw ∈ TW
    for each vi ∈ V in fj and fk having weight w1,w2
        if w1 ≠ 0 AND w2≠ 0
         impose w1≠w2
        end if
      end for
end for
```

a) Algorithm for Solving Constraint 5

ALGORITHM 2—CONSTRAINT 6

```
let Coef be a coefficient of Vi =[1,2,3….,Vn]
 ∀f∀v  compute fv=foi ×Coef
for any fj, fk ∈ F having value fv1, fv2
        if fv1 ≠ 0 AND fv2≠ 0
         impose fv1≠fv2
        end if
      end for
```

b) Algorithm for Solving Constraint 6

It is noted that if 10101 indicates an allocation of vehicle #1,#3,#5, it produces fv= 1+3+5=9.

ALGORITHM 3-CONSTRAINT 1&7

```
For all fleet[order i][Day j]
     For all vehicle_k
          IF order_i <Incompatible with vehicle_k>
                 Impose w_k=0 ( Constraint 7)
          End If
                 Impose  w_k= X|X ∈ W  (Constraint 1)
     End For
End for
```

c) Algorithm for Solving Constraint 1&7

ALGORITHM 4— CONSTRAINT 2

For all fleet[order $_i$][Day $_j$]

sumweight[order $_i$][Day $_j$] = $\sum_{a=1}^{K} wa$

Impose sumweight $\geq \text{min\_fleet}$ || sumweight ≤ 0

End for

d) Algorithm for Solving Constraint 2

Figure 4- 7: Algorithms for the constraints 1, 2, 5, 6, and 7

4.5 Optimal Search Strategy, Validation, and CP Investigation

The three experiments were conducted on the developed system to investigate certain issues. The first experiment was conducted to investigate the optimum search strategy for fine-tuning the system. The second experiment was conducted for validation purposes to investigate the functionalities and generalisation of the proposed method. Finally, the third experiment was conducted to observe the internal variables and mechanism of the CP when solving problems. Each experiment was run on an Intel® Core™ i5CPU M450 2.40 GHz. Considering the practicality in returning search results for real time decision making, the searching time of every experiment set to a limit to 2 Second.

4.5.1 Optimal Search Strategy

As mention earlier in Chapter 4.2 the CP research using the B&B algorithm in Choco solver, there are several possibilities in defining the search strategy. The first experiment is to evaluate the effects of applying different search strategies of CP when it solves the identified problem. Ultimately, the optimal strategies can be defined. Several parameters defined in Table 4-2, Table 4-3 and Table 4-4 are used to compose 40 combinations of search strategies to investigate their performances as shown in Table 4-7.

Table 4- 7: Evaluation of Different Search Strategies

SN	B	VS	VIS	ANS
1	1	A	I	NS
2	1	A	Ii	NS
3	1	A	Iii	NS
4	1	A	Iv	NS
5	1	A	V	NS
6	1	B	I	30
7	1	B	Ii	NS
8	1	B	Iii	30
9	1	B	Iv	70
10	1	B	V	NS
11	1	C	I	NS

Table 4-7: Cont.

SN	B	VS	VIS	ANS
12	1	C	Ii	NS
13	1	C	Iii	NS
14	1	C	Iv	NS
15	1	C	V	NS
16	1	D	I	10
17	1	D	Ii	NS
18	1	D	Iii	10
19	1	D	Iv	NS
20	1	D	V	NS
21	1	E	I	30
22	1	E	Ii	NS
23	1	E	Iii	30
24	1	E	Iv	70
25	1	E	V	NS
26	1	F	I	NS
27	1	F	Ii	NS
28	1	F	Iii	NS
29	1	F	Iv	NS
30	1	F	V	NS
31	1	G	I	30
32	1	G	Ii	NS
33	1	G	Iii	30
34	1	G	Iv	70
35	1	G	V	NS
36	2	-	I	NS
37	2	-	Ii	505
38	3	-	Iii	NS
39	3	-	Iv	470
40	3	-	V	498

It is noted that NS represents the strategies that produce a 'No Solution'.

In the experimental scenario, the company receives 4 different orders from customers with a demand of 200, 250, 400, 500 tons. Other problem parameters are the similar to those defined in Table 4-6. Three iterations were run to find an average answer. From Table 4-7, there were only 14 out of 40 combinations that can produce answers. This is because the search operation in this experiment is limited to 2 seconds which is the intention of the experiment to find an optimal search strategy that can produce an answer quickly for a practical application. If the search time is relaxed, more solutions could be produced. There are 2 search strategies produced equally the best answer from the experiments which is SN16 (MinDomain/DecreasingDomain) and SN18 (MinDomain/ MaxVal). One of the scheduling results (SN16) is shown in Table 4-8.

Table 4- 8: Resulting of SN16

Fleet No.	Vehicle No/Weight	Order	Amount	Depart
1	1/35,2/35,3/35,4/35,5/30,6/30	1	200	1
2	7/35,8/35,9/30,10/30,11/30,12/30,13/30,14/30	2	250	1
3	15/35,16/35,17/35,18/35,19/35,20/35	3	210	1
4	1/35,2/35,3/30,4/30,5/30,7/30	3	190	5
5	6/35,8/35,9/35,10/35,11/35,12/35,13/35,14/35,15/35 16/35,17/35,18/35,19/35,20/35	4	490	5

4.5.2 CP Validation

Experiments were conducted to validate the implemented system to investigate whether the system delivers proper functionalities and having adequate generality to solve different problems. There are three scenarios to test as following details:

Scenario 1: A company owns 20 vehicles. The vehicles are all the same model. The minimum load is 30 tons, and the maximum capacity is 35 tons. A company receives 3 orders with a required amount of 320,450, and 600 tons respectively, and each order requires different amount of time to make a delivery which are 1 day, 3 days, and 2 days, respectively. The expected outcome is the assigned vehicles will not assign any tasks within their delivery time windows.

```
Order 1  35 35 35 35 30 30 30 30 30 30 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 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|
Order 2  0 0 0 0 0 0 0 0 0 0 35 35 35 35 35 35 30 30 30 30| 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0| 30 30 30 30 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|
Order 3  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 35 35 35 35 35 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 35 35 35 35 35 35 35 35 35 35 35|

         subcontractor to be hired for order 1:  0
         subcontractor to be hired for order 2:  0
         subcontractor to be hired for order 3:  40
```

Figure 4- 8: The Result of CP Validation using the Scenario 1

The output generated from the system is located in the layout as shown in Figure 4-8. It demonstrates the result of scenario1. From Figure 4-8, the fleet is represented by an array of digits i.e. there are 20 digits in this example. The position of digits indicates the fleet members which are a set of vehicles {v1, v2 ,..v20}, the value represents weight wi for each vehicle, and a summation of digits in each block is a fleet size. There are 5 blocks of fleets representing 5 days scheduling ("|" is a fleet separator). When number of vehicles in the company is not enough to cover the orders, subcontractors who can contribute surplus weight W* can be used as indicated on the bottom of Figure 4-8.

The example of the output interpretation is that the vehicles #1-#10 are dispatched on the first day of scheduling for the 1st order, the vehicles #1-#4 will load 35 tons of grain, and #5-#10 will load 30 tons of grains and so on. As the 1st order is only required 1 day to delivery this means the vehicles return back on the same day in case of the first day of delivery. However, the vehicles #1-#10 will require 1 more day to allow the drivers to have a rest before the next assignment. The vehicles #1-#4 are assigned the next delivery task to dispatch in the third day and they will require three days for this delivery. Similarly, the vehicles #5-#9 are also dispatched on the third day, and they will require 2 day for making delivery. The vehicles #11-#20 are firstly dispatched on the first day of schedule, they require 3 days of delivery, and therefore they are given another assignment on the fifth day to make deliveries for the 3rd order. The company requires hiring subcontractors to deliver 40 tons for the 3rd order. The experiments indicate that the proposed method provides valid results by not assigning a new delivery task to vehicles that are on delivery.

Scenario 2: A modification of the scenario 1 to test that if some vehicles are not allowed to make delivery for some specific orders. The scenario assumes that vehicles

#1,#2,#3,#8,#9,#10 are not allowed to deliver the 1st order. Those vehicles are not expected to contribute any load for the order #1.

```
0 0 0 35 35 35 35 0 0 0 30 30 30 30 30 30 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 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|
35 35 35 0 0 0 0 35 35 35 0 0 0 0 0 0 30 30 30 30| 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0| 0 0 0 30 30 30 30 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 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 35 35 35 35 35 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| 35 35 35 0 0 0 0 35 35 35 0 0 0 0 0 35 35 35 35 35|

subcontractor to be hired for order 1:   0
subcontractor to be hired for order 2:   0
subcontractor to be hired for order 3:   40
```

Figure 4- 9: The Result of CP Validation using the Scenario 2

The results from the scheduling in Figure 4-9 indicate that those limited vehicles are not assigned loads to the 1st order. For example, the 1st order is assigned to the vehicles #4,#5,#7,#11,#12,#13,#14,!5, and #16. However, those vehicles are eligible for the other orders, they are assigned to deliver load for order 2 and order 3. Therefore valid results of this experiment are produced.

Scenario 3: the scenario is to test if the company owns various vehicle sizes; the scheduling still generates the valid result. Assuming that the company has 3 types of vehicles; the vehicles #1-5 have the minimum/maximum load 20/25 tons, the vehicles #6-10 have the minimum/maximum load 28/30 tons, and the vehicles #11-20 have the minimum/maximum load 32/35 tons. The expected results are to show the assigned weight to each vehicle is in the valid range

```
25 25 25 25 25 30 30 30 30 30 35 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 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 35 35 35 35 35 35 35 35 35| 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0| 25 25 25 25 25 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 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 30 30 30 30 30 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 35 35 35 35 35 35 35 35 35 35|

subcontractor to be hired for order 1:   10
subcontractor to be hired for order 2:   10
subcontractor to be hired for order 3:   100
```

Figure 4- 10: The Result of CP Validation using the Scenario 3

The generated schedule in Figure 10 indicates the valid assignment. For example, for the delivery of the 1st order in the first day, the vehicles #1-5 are assigned to load 25 tons of grain, #6-#10 are assigned to load 30 tons of grain, and the vehicle #11 is assigned to load 35 tons of grain.

4.5.3 CP Investigation

In the final experiment, various search conditions are generated to apply to the developed system to observe the search mechanism. Primary variables as defined in Table 4-6 are used associatively with the search conditions supplied in Table 4-9. Tc denotes a test case number, O1-O4 are order numbers, and Dur (days) denotes duration of the delivery

Table 4- 9: Search Parameters for CP Investigation

Tc	O1	O2	O3	O4	Dur	MinF	MaxH	Sc
1	500	-	-	-	3	70	150	-
2	500	500	-	-	3	70	150	-
3	500	500	500	-	3	70	150	-
4	500	500	500	500	3	70	150	-
5	250	400	500	300	3	80	50	<O1!:v1,v2> ,<O2!:v3,v4>
6	250	400	500	500	2	80	50	<O1!:v1>

Table 4-10 indicates an internal mechanism of the developed CP scheduling where various search conditions are applied. For example, the Test Case 1 is associated with 210 variables and 396 internal constraints, there were 182 nodes generated for the search, and it was backtracked totally 93 times. Running the Test cases 1-4 showed that when an order is incremented the variables and the constraints of the system increase massively, while an expansion of node and backtracking times are not relatively affected. Test cases 5-6 were used to observe the developed system when the Side Constraints are imposed. The Test case 6 indicated that when the problem is ‘over constrained’, a solution cannot be generated.

Table 4- 10: Internal Mechanism of the System

Tc	Variables	Constraints	Nodes	Backtracks
1	210	396	182	93
2	418	1389	473	319
3	626	2982	1717	4402
4	834	5175	1200	3528
5	834	5395	1461	2565
6	No Ans	No Ans	No Ans	No Ans

4.6 Discussion

The results of this research indicate a primary success in applying the CP to solve the described agricultural scheduling problem. The advantages of the method include:

1) **Scheduling can guarantee producing at least a partial solution if feasible solutions exist**

Unlike other classical methods of tackling this problem, the proposed method can guarantee to produce a solution. Even if sometimes the solution is only partially optimal it can be guaranteed that the decision maker will get some information to support a decision making in a given time. Regarding the proposed CP implemented B&B algorithm, the process of generating a solution is traceable. When the operation time is adjustable, as shown in the experiments in Chapter 4.4.1, 4.4.2, and 4.4.3 that the method can produce a good answer even if the operation time was limited to two seconds, the operation time can be adjusted to fit the problem. For instance, the operation time can be increased a little further to increase the chances that a better answer is found.

2) **Schedule is Produced in Advance**

Compared to the current operation where the schedule is a daily FCFS base, the proposed method generates a plan for future delivery. The obtained benefits are if the schedule operates to plan, a manual scheduling which is currently a routine job of a decision maker will not be required. Also scheduling beforehand can improve the efficiency of vehicle utilisation significantly. Finally, the proposed method can provide more efficiency and flexibility in delivery. For example, the current operation involve the company commitment to customers to complete delivery in 7-10 days; the proposed method can be used as a 'what-if' tool to improving the delivery time e.g. 5 days to improve customer satisfaction.

3) Inefficiencies of FCFS can be Resolved

The major disadvantage of FCFS is to consider nothing else when scheduling apart from queuing. This can lead to losing of efficiency in the following scenario.

There are 4 vehicles in the queue. Each of them has the maximum capacity of 35, 35, 35, 30 tons respectively as indicated in Figure 4-11. The requirement is to deliver 100 tons of grain.

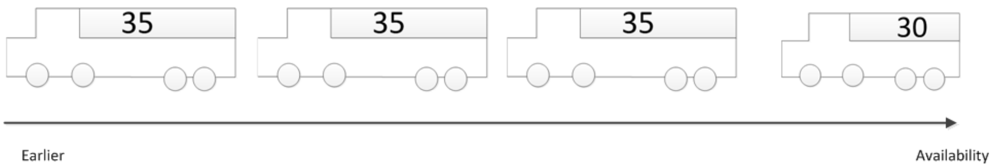


Figure 4- 11: The FCFS Scheduling

The manual FCFS will allocate the vehicles in the way showing in Figure 12 which will cause a lack of efficiency in loading to one of vehicles i.e. loading 30 tons to the 35 ton vehicle

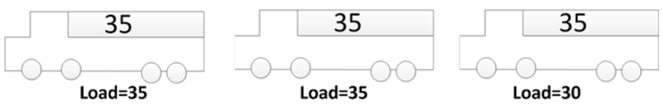


Figure 4- 12: Manual FCFS Allocation for 100 Tons Loading

The proposed method will allocate vehicles without considering the sequence of availability. It will allocate vehicles as shown in Figure 13, which will make all vehicles have a full load.

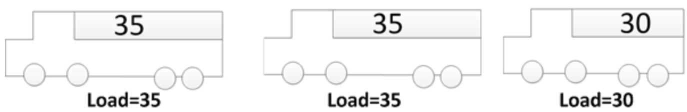


Figure 4- 13: CP - Based Allocation for 100 Tons Loading

4) Minimum load level can be guaranteed

Another advantage of the proposed scheduling is it can guarantee a minimum loading level which can overcome another kind of inefficiency as indicated in the following scenario.

There are four vehicles available; each of them has a maximum capacity of 35 tons. The requirement is to deliver 120 tons of grain.

In the manual scheduling, vehicles tend to be assigned to full capacity. So, it is likely that this allocation will assign the fleet as indicated in Figure 4-14.

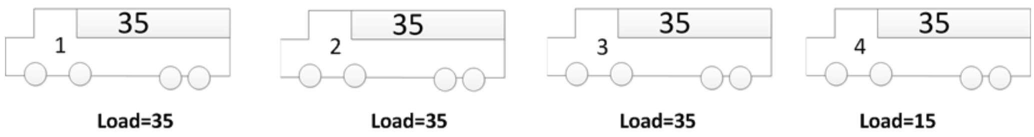


Figure 4- 14: Manual FCFS Allocation for 120 Tons Loading

It can be seen that vehicle #4 is only loaded 15 tons, while the other 3 have a full load. This is not only leading to a lack of loading efficiency of vehicle #4, but it also reflects unbalancing of asset utilization.

The proposed method enforces a constraint for the lower bound domain of loading, e.g. Lower bound =30 tons and Upper bound =35 tons. Therefore, it is likely to generate the allocation as indicated in Figure 4-15 where vehicles are utilised giving loads equally.

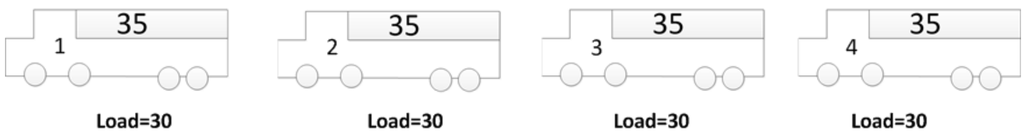


Figure 4- 15: CP- Based allocation for 120 Tons Loading

However, there is an issue on the using CP implementing B&B solving the problem as the CP Investigation experiment indicates that the number of variables has no relationship to the number of nodes and backtracking time. For example, running the test cases 1-4 showed that when an order is incremented the variables and the constraints of the system increase massively, while an expansion of nodes and backtracking times are not relatively affected. This, on one hand, indicates the advantage of implementing B&B in CP that allows a search space to be pruned subjecting to the search conditions. Alternatively, it can indicate a limitation of the proposed method in estimating its complexities to generate solution.

4.7 Summary

The main contribution of this chapter is applying the Constraint Programming (CP) for long-haul agricultural transport in scarce resource environment. Constraint programming (CP) is a programming paradigm used for modelling and solving problems with a discrete set of solutions (Lozano, 2010). The chapter contributes a discussion of CP modelling for the employee rostering problem. It then illustrates an implementation of B&B for CP. CP for optimal fleet scheduling was investigated. The chapter presented the subcontractor optimisation problem for a fleet scheduling by giving a problem specification, problem representation, the hard constraints and the soft constraints (objective function) of the problem, variables and domain of the proposed method, the implementation using Choco API discussing the constraint network and the sub-algorithms associated with the constraints. The chapter then outlines the experimental tests. The first test was conducted to evaluate different search strategies. It was found that two specific strategies produced equally the best answers which are (MinDomain/DecreasingDomain) and (Mined Domain/MaxVal). The second test was conducted for testing the functionality and the generality of the proposed method for the fleet scheduling. The results indicated that the proposed system can deliver valid results for every tested scenario. The final test was conducted to observe the internal variables when the system operates. The chapter also discusses the results from the experimentations using CP for a fleet scheduling. There are several advantages of the proposed method. The proposed method can be used to enhance an efficiency of transport logistics management including: the system can guarantee producing solution, if feasible solutions exist, schedule is produced in advance, inefficiencies of FCFS can be resolved, and the minimum load level can be guaranteed. However, there is an issue from the experiment 3) showing the number of nodes and backtracking time are independent and do not relate to the number of variables in a constraint network. In the next chapter, Chapter 5, the discussed CP method will be integrated with RFID technology previously studied in Chapter 2 to produce a further advanced real-time scheduling system.

Chapter 5

The Proposed Tracking and Scheduling System for Agriculture Company

5.1 Introduction

The research conducted in this chapter is based on a real problem from an agriculture company in Thailand called Peuchpol Suvanabhum (PPS) and an Approval letter for the research is given in Appendix-1. This chapter investigates the three-phase system development described below. In phase 1, the research conducts a problem survey covering the company's background, encountered problems, and the company's existing technologies. The investigations from phase 1 leads to the study in phase 2: Design and Implementation involves an integration of two key Information technologies discussed previously in Chapter 3 (RFID) and Chapter 4 (Constraint Programming) covering hardware, software, data organisation, and process engineering aspects. The last phase investigates the research validation process to ensure the validity of the proposed method. The chapter also discusses the aspect of system transformation, particularly on how the proposed system can be expanded further.

5.2 Phase1 - Problem Survey

The survey was conducted with the case study company in Northern Thailand called Peuchpol Suvanabhum (PPS) Co. Several techniques were used for gathering information of the company including a field observation for understanding their general business process, semi-structured interviews conducted with key people of the company including: the owner who is the Chief Executive Officer (CEO) of the company and the key operator of each department to discuss the company background, current practices, problems encountered and the tools currently used by the company. Some questions are redundantly queried from several stakeholders to validate and amend the answers to completion. The interviews were informal with guided questions as shown in Figure 5-1.

Owner (CEO)	Management staff
- Business background of the company - Administration structure - Encountered problems and solutions - Business constraint	- Adopted technologies and planning strategies - Encountered problems and solutions - Number of Vehicle and capacities - Constraints - Task procedures - Samples of orders - Sample of scheduling

Figure 5- 1: List of Topics for a Semi-Structured Interview

5.2.1 Company Background

Peuchpol Suvanabhum (PPS) Co. Ltd is one of the largest wholesale agricultural companies in the North of Thailand trading corn, green beans and soy beans as main products. The company was originally started from a small family-run business in 1976. Currently, the business is under the management of the second generation of the family and registered as a company from 1992. The business of the company has been growing successfully. At the peak period, 2,000 tons of crops are delivered daily in different locations around Thailand and the annual revenue of the company ranges from £12-16m.

PPS has three businesses including farmer financial loans, delivery service, and grain trading, but the core business is the grain trading. The other two businesses have branched out to support the core business. For instance, the financial loan is a business where the company loans out agricultural resources such as fertiliser, seeds, and sometimes financial support to the local farmers to improve farmer liquidities in supplying grain to the company. The delivery business has been introduced lately to resolve an empty backhaul problem the company encountered when delivering grains to customers. As the focus of the research includes a proposed a solution to solve the agricultural logistics issues, the core business of the company is focused, and their logistics process is depicted in Figure 5-2.

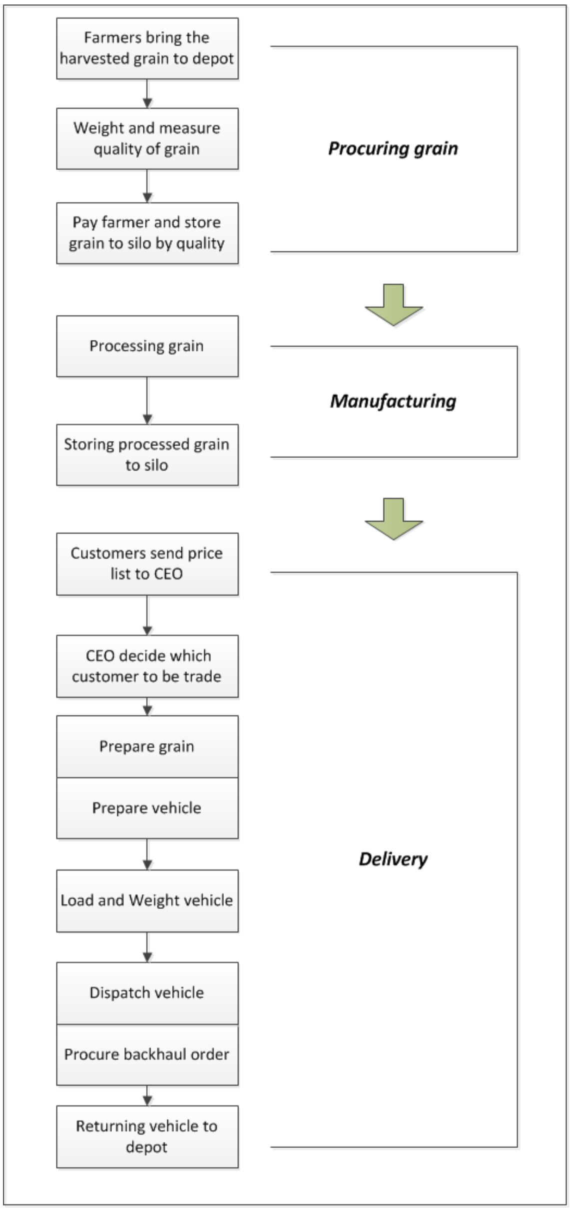


Figure 5- 2: Logistics Process of PPS

There are three primary logistics processes: Firstly, the grain procurement is started when the local farmers bring their harvested crop to the depot, normally using their own vehicles. Each vehicle is then weighed to measure the crop weight (i.e. computed from total weight – vehicle weight). The crop is checked to grade it and estimate the price by considering quality and humidity. The farmer is then paid, and the crop is sent to store in a silo by grade to wait for a processing. The second process is the crop processing. Each kind of crop requires the different production processes. For example, corn requires shredding to remove the grain and then removing humidity. Soy beans and green beans require size screening. Then, the processed grains are stored in the other silos for either stock-piled or sold. Finally, the selling process is initially started by the customers (mainly food manufacturers) daily who will send a buying price of each grain type (e.g. 1st grade, 2nd grade, 3grade, etc.) to the owner of the company via Short Message Services (SMS). If the CEO of the Company decides to sell the grain, they will check the amount of grain in stock from the company records, then trade the grains over the telephone and inform the transport department to process door-to-door deliveries to customers. Usually the company commits to the customers to complete deliveries in 7-15 days depending on the volume. The dispatch of the transport, on every day after receiving an order, will check stockpiles and the availability of vehicles, then assign the vehicles to make a delivery. The subcontractors might be used if available vehicles are in shortage. The assigned vehicles will go to load grain from the warehouse. After, loading the vehicle will be weighed to update the exact tonnage. Next, the vehicle dispatch to the customer's factory, meanwhile staff in a transport department start to procure a backhaul order. After that, the vehicle unloads grain then rides to pick up goods, and unload goods if the backhaul order is received. Finally the vehicle returns to the depot to wait for a next assignment.

5.2.2 Administration Structure

The company has a flat administration structure. The topmost level is the owner of the company who also acts as CEO. There are 6 departments under the CEO as depicted in Figure 5-3.

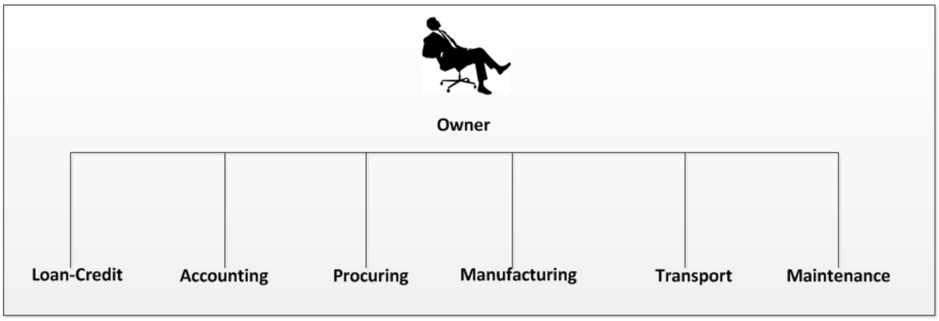


Figure 5- 3: Administration Structure

The job description of each department is shown in Table 5-1 as follows:

Table 5- 1: Job Description of each Department

Department	Responsibilities
Loan-Credit	Proceed loan and credit to local farmers
Accounting	Accountings of the company including :, agricultural account, delivering account
Procuring	Buying grain from local farmers
Manufacturing	Processing raw grain to end product
Transport	Transportation process
Maintenance	Maintaining machine and vehicles

5.2.3 Company Assets

This session investigates the two assets including vehicles and current information technology.

Vehicles

The company owns primarily two types of vehicles - fixed-type and articulated –type vehicles. Each of them has its own advantages over the other type. For example, the advantage of the fixed-type vehicles is that the vehicles are easy to maintain, and consume less fuel, while the articulated-vehicles can deliver more tonnages and have an ability to manoeuvre to most of the premises. Dumper trucks are a sub-category of the fixed-type vehicles, but have a special feature of dumping to unload grains. Also, another advantage of the articulated vehicles over the fixed vehicles is that vehicles can be split weighed in case where customer has a short weigh scale when selling products to the customer, whereas using a fixed-type vehicle always requires a long weight scale as demonstrated in Figure 5.4.

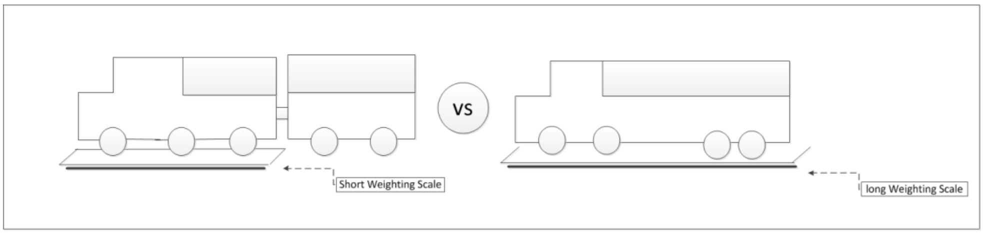
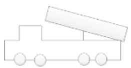


Figure 5- 4: Vehicle Type and Weighting Scale Required

The comparison of different types of vehicles is summarised in Table 5-2. The criterion includes a physical appearance, amount that the company owns advantages and disadvantages of each category.

Table 5- 2: A Comparison of Vehicle Categories Owned by the Company

Type	**Appearances**	**Amount**	**Advantages**	**Disadvantages**
Fixed		7	- Easy to maintain - low fuel consumption - Applicable to small amount of order	-Not applicable to small weighting scale -Not applicable to small premise
Articulated		13	- Large capacity - Good manoeuvre - Applicable with small weighting scale	- Require more maintenance - high fuel consumption - loose efficiency when used for small load
Dumper		3	- Same as fixed vehicle, plus a dumping feature	- Same as a fixed-vehicle

Company Information Technology

The company as detected difficulties in vehicle part replacements and petrol shrinkage problems and GPS-based tracking system has been installed to monitor the company's vehicles using the system called "Onetrack". The tracking system enables the company monitor an individual vehicle, e.g. the current location, the mileage, the speed, etc., during its journey. That can help the company detect incidents caused from the driver behaviour i.e. when the drivers stop during the journey, takes a detour, or drives exceed the speed limit, appropriate actions can be taken in real-time by staff that monitor the journeys. The summary of routes can be viewed also when the journey is finished. A screenshot of the system is shown in Figure 5-5.

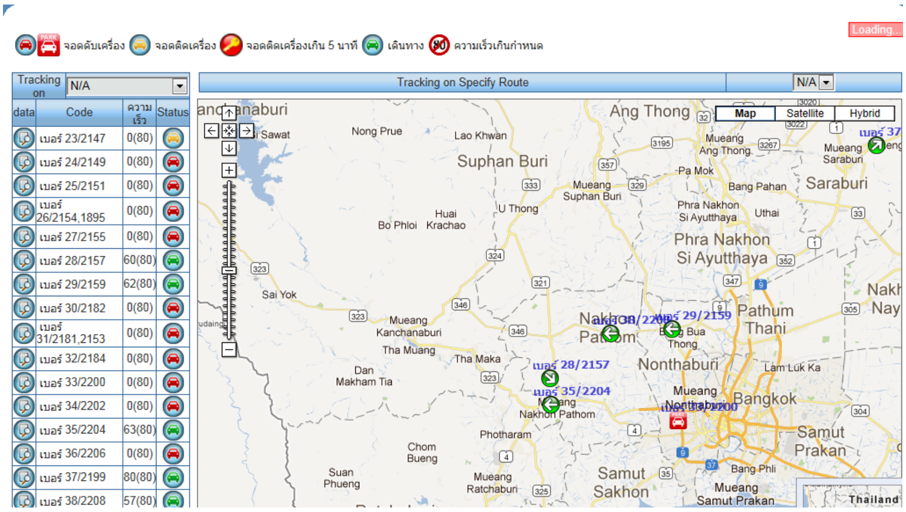


Figure 5- 5: Screenshot of the Onetrack System

5.2.4 Identified Problems

The field investigation was conducted by several interviews and observations as indicated in Figure 5-6. The results have shown that the company mainly performs each logistics process manually. This information is not stored in a centralised way and each department tends to hold individual copies of the data. When the process activity is transferred from one to the other, direct human interaction is always required. Consequently, there is no best practice regarding system flow. Decision making is fully reliant on human experience and this can vary depending on the person. In summary, performance in terms of productivity could be improved if scientific and systematic approaches, i.e. with the use of Information Technology, were introduced to support the activities outlined.

Figure 5- 6: PPS Field Studies

The field survey investigation divides the problem into two main categories: technical problems and management issues.

Technical issues

The technical issues include problems that have been identified by the company staff and are as follows:

1) Empty backhaul

Empty backhaul is a situation in which, after the company has delivered products to a customer, the truck returns to the yard empty. This increases operational costs and reduces profitability. To overcome this, PPS promoted themselves as a freight forwarder who can provide the delivery service to other companies who wish to deliver products near to the company region. However, it is considered to be a challenging trade-off by the company to undertake this new business operation.

2) Petrol shrinkage

Driver loyalty is another critical issue as the company loses money if petrol is stolen by drivers. The drivers in some fleets conspire to steal petrol which they sell to illegal petrol stations.

3) Freight rejection

Freight rejection is a situation in which the customer asks the company to re-deliver a better quality of products. The problem occurs because of an error in the grading process before delivery. Crop grading at PPS is operated by human justification with basic laboratory operations, while the customers, who are food producers, have higher performance standards for validation.

4) Employee loyalty

The owner of the company has identified that employee loyalty is one of the most critical and challenging issues to the business. There were the cases in both managing and operational (i.e. driver) staffs. A manager was caught selling the order to a rival company. The drivers have been found smuggling stolen vehicle parts and petrol during the delivery.

To steal petrol successfully, all drivers in the fleet need a conspiracy to fool the company they consume the same amount of petrol which will multiply the effect of petrol shrinkage.

Management Issues

Management issues, unlike technical problems, are likely to be ignored by the company. The typical issues that were detected during the survey are as follows:

1) Lack of information sharing

Each unit of work is operated individually. Operators are familiar only with their holding data. Information is kept on the separate physical storage devices i.e. book, spread sheet, hard disks. Also, the stored data tends to have no standards. the data definition is based on the data holder's understanding.

2) Too much paperwork produced

Documents are mostly paper bases. Several documents and reports serve only specific purposes. Some of them contain duplicated information. As a result, retrieving and updating the existing data is very difficult.

3) No automatic work flows

Each transition process is passed on by direct human communication. There is no automatic flow for routine tasks. As a result, there is no best practice framework for routine processes. Performance of each task depends completely on the decision maker's justification. Also human intervene is always required.

4) Optimal decision cannot be guaranteed

Due to the lack of computer assistance in planning, a plan and decision is highly dependent on human skills which cannot guarantee that the decision is made based on a proper and systematic logic of an optimal thinking-particularly when the problem is large and complicated, or when a newly-trained planner makes a decision. Currently, only a simple First Come First Serve (FCFS) is considered which rarely considers some other optimal issues in logistics.

5) Difficulties in knowledge transfer

The effectiveness of the existing system relies highly on the skills and experience of the knowledge-worker who will make the decision. That also means it is difficult to pass the task to other people when necessary e.g. when an employee is on holiday or leaves the company. In the case of the business itself, it might be difficult for the next generation to continue this family business, as the owner has three children who have not begun involvement with the business yet.

5.2.5 Justification of Research Focus

The problem study and analysis indicate that several problems can impede efficiency of the logistics operation of the case study. This research cannot tackle all the detected problems and some problems cannot be even solved by IT but requiring a manufacturing process and administration strategies etc. However, the major problems can be solved by an integration of the real time sensors and a Decision Support System (DSS) operating optimal computer algorithms. These are the focus of this research which has been outlined in the section with the encountered problems, and possible solutions which are summarised in Table 5-3.

Table 5- 3: Encountered Problems with Possible Solutions

No.	Problems	Application/ solution required
1	Empty backhaul	Balancing a line-haul and back-haul
2	Employee loyalty	Asset traceability
3	Freight rejection	Product quality control
4	Lack of information sharing	Computer based Information system
5	Too much paperwork produced	Computer based Information system
6	No automatic workflow	Sensor + Computer based Information system
7	Optimal decision cannot be guaranteed	Optimal computer algorithm
8	Difficulties in knowledge transfer	Optimal computer algorithm

The research focuses on the scheduling applications ability to process rescheduling if required. Regarding the transport logistics, it is possible that the plan requires revision, for example, a new order is received, the assigned vehicle is not returned on time, and vehicles break down on their way to deliveries. These types of situations occur in practice so it is important that a new schedule can be generated effectively to replace the existing one as soon as possible.

5.2.6 Assumptions of the Proposed Method

To simplify the research and limit the research scope, the following assumptions were made.

1) Backhaul delivery is not considered

The company operates a single depot transportation system; a backhaul delivery is the only option which means a vehicle is allowed to return with an empty load i.e. due to the backhaul order is procured only after the vehicle is dispatched from the depot. The company might not receive any backhaul orders. As agricultural supply is a main business of the company, when there is a high volume of grain orders vehicles are required to return straightaway to deliver a new order without considering backhaul deliveries. Therefore, it is not possible to plan a backhaul delivery in advance due to a restriction of the current business rule.

2) Maintenance is not considered

In reality, when a vehicle returns to a depot, it sometimes requires a repair or planned maintenance before a new assignment can be given. In this research, it is assumed that the vehicle is always in a good condition to be used. For a practical usage, the system requires further expansion by deploying another set of RFID readers to monitor the maintenance process at the garage i.e. the vehicle will be ready to be used when it leaves the garage.

5.3 Phase2 - Design and Implementation

The problem survey in the previous phase, Chapter 5.1 of the study, leads to the proposal of a system that can resolve some high-impact problems that the company has encountered. In this phase, the study focused on the system design and implementation and will concentrate the discussion on the hardware, software, data organisation, and process engineering as the following details.

5.3.1 Overview of the Proposed System

The research proposes a real-time data collection technology enabled information system to provide optimal real-time decisions as shown in Figure 5-7. The components of the proposed system are

1) RFID technology - to collect a real time data of vehicles
2) Database - to provide information for decision making
3) 2 subsystem (decision support) software - including 3.1) scheduling subsystem and 3.2) vehicle tracking subsystem for a process monitoring.

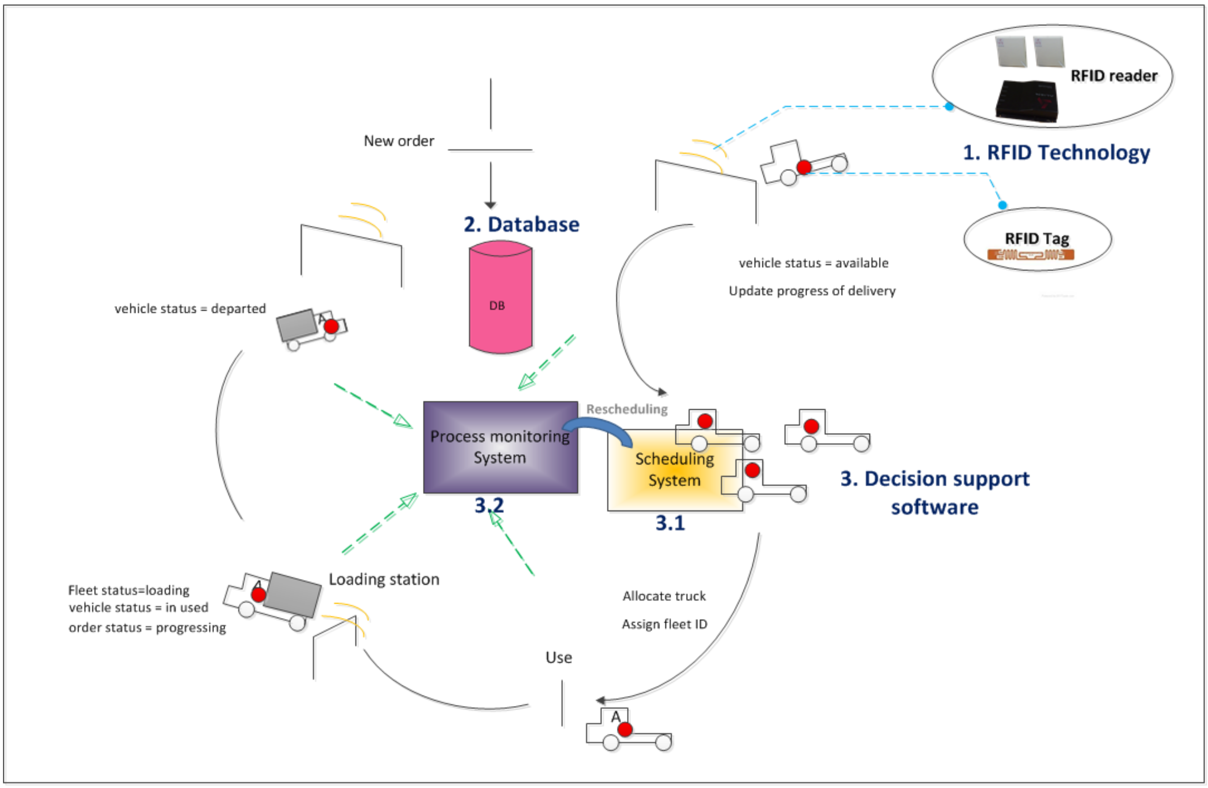


Figure 5- 7: The Proposed System Overview

A cycle of vehicle utilisation is when a vehicle returns from delivery and waits in the depot. It waits to be called to load grain from the loading station. Finally, it will be dispatched for delivery. The process monitoring is used for monitoring and updating progress in the depot. The real time status of the vehicles is identified by the RFID technology.

When an order is received, it will be stored in a database. A scheduling subsystem associated with a process monitoring subsystem retrieves available vehicles, to compute the schedule.

5.3.2 Hardware Design

Figure 5-8 indicates the physical layout of the case study with the proposed RFID technology deployed to identify the vehicles. Regarding the deployment of the RFID which is primarily for identifying availability of vehicles, therefore technically installing only one RFID reader at the gate is adequate for that purpose (RFID 1 in Figure 5-8). However, the system can be easily expanded for depot management in future by installing further RFID reader devices throughout the depot. This would allow vehicles to be identified anywhere in a depot e.g. warehouse, administration office, security lodge etc. to specify their real time activities to provide a better decision support.

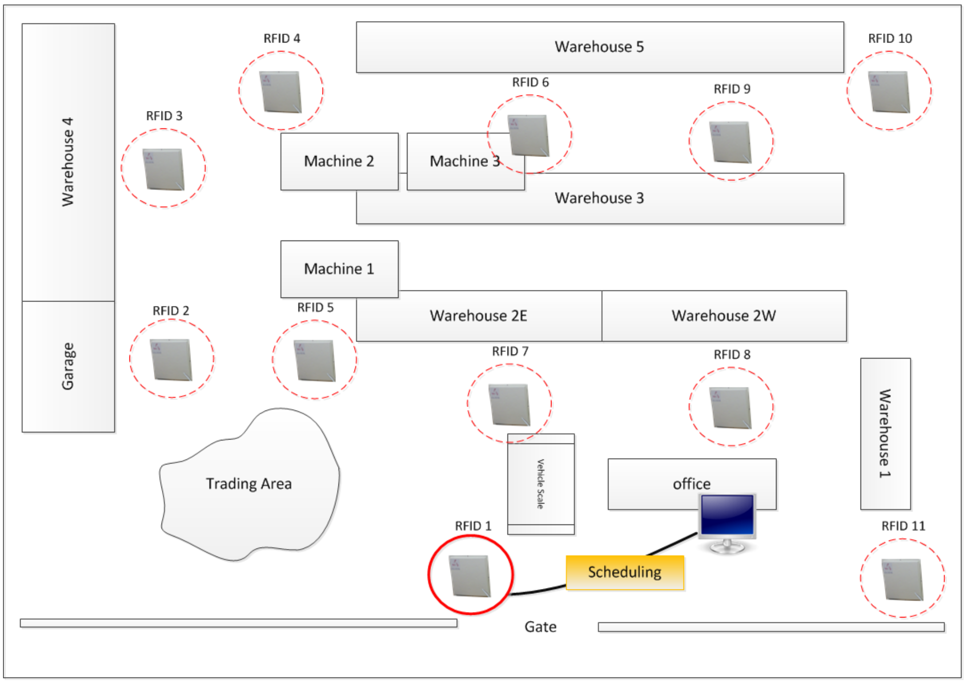


Figure 5- 8: The Deployed of RFID Technology

Principally, instead of deploying an individual set of RFID readers at each location in the depot, a combination of antenna and reader identification can be used to reduce investment on RFID hardware significantly as indicated in Figure 5-9. However, the limitation of the current technology is that the physical wiring connections between antenna and the reader, which is usually short. The various configurations will be implementable when those limitations are resolved e.g. wire lengths, or a reader and antenna communicating with each other wirelessly.

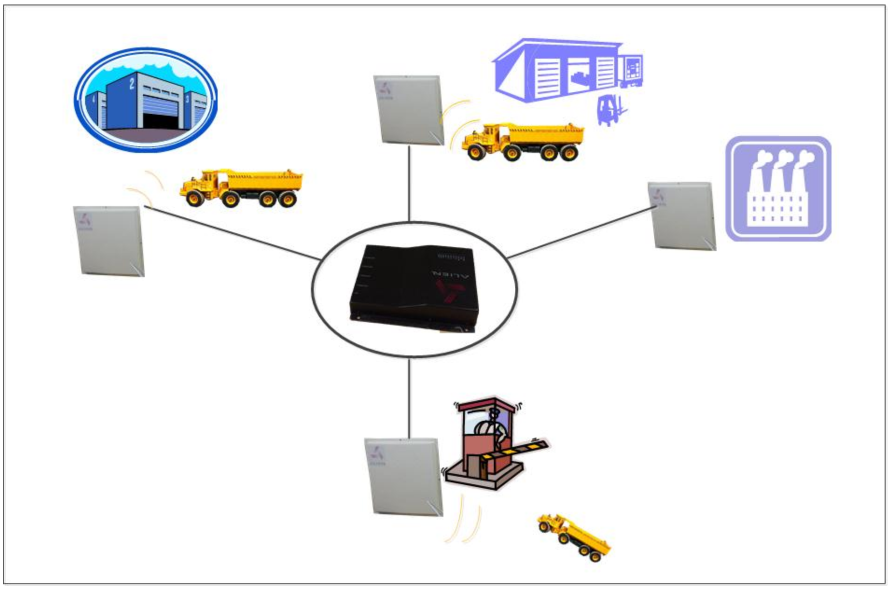


Figure 5- 9: A Combination of using Antenna ID and Reader ID to Represent Unique Location

When the systems enabling the antenna to perform both read and write operations is deployed, and a reader can connect up to N antenna, and there are M readers, the system can identify M × N different locations. Table 5-4 demonstrates a case of 2 readers, each of which can connect up to 4 antennas, and therefore, the system can identify 8 different locations.

Table 5- 4: Combinatorial of Using 2 Readers and their 4 Antennas to Identify Locations

Readers	Antennas	Locations
A	1	Entrance
A	2	Security lodge
A	3	Factory1
A	4	Factory 2
B	1	Warehouse
B	2	Truck terminal1
B	3	Truck terminal2
B	4	Exit

5.3.3 Software Design

The proposed system has two subsystems: subsystem 1 is the vehicle tracking and subsystem 2 is the scheduling. The tracking subsystem was developed to identify the activities of a vehicle in a depot using RFID technology. The identified activities can infer the availability status of the vehicle, which can be used for another purpose to input to the subsystem 2 for the scheduling to produce an optimal fleet schedule. After that, RFID is also used to verify that the delivery operation is on schedule, if not it will trigger a rescheduling request. The association of the two subsystems and other technologies e.g. database and RFID technology, is shown in Figure 5-10.

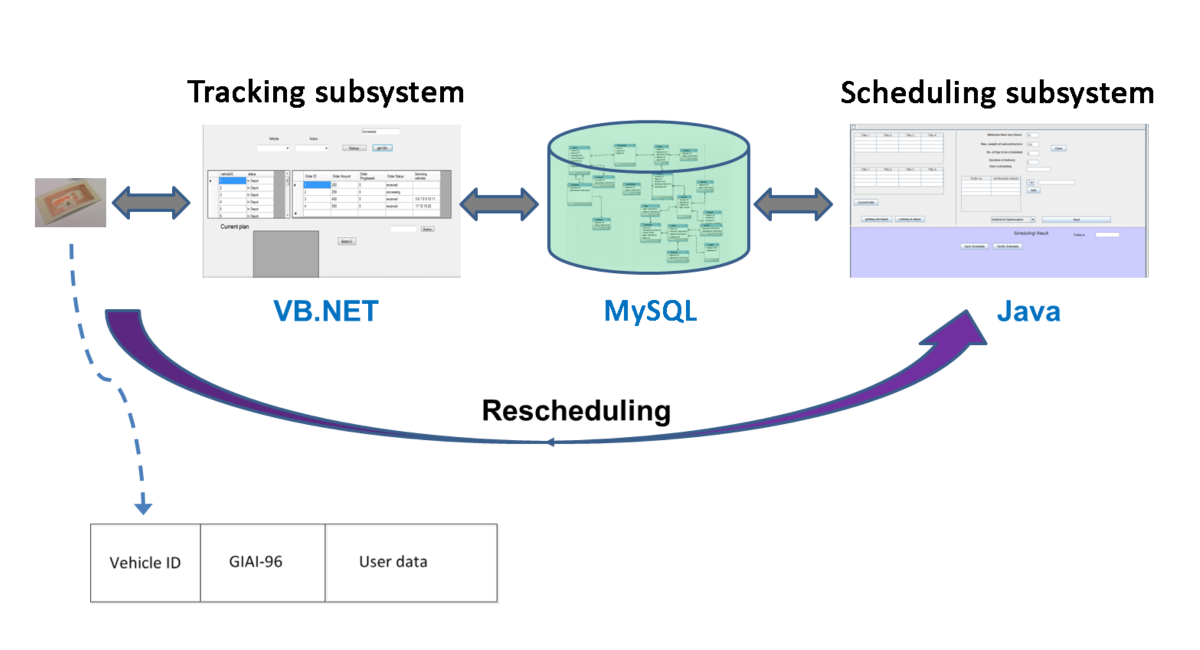


Figure 5- 10: The Software System

1) The Tracking Subsystem Design

A tracking subsystem based on the RFID data acquisition in Chapter 2 has been developed for monitoring vehicles in the depot areas. It is used to identify the activities of vehicles in a depot. The subsystem was developed using Visual Basic.Net 2010. It is associated with a RFID reader controls the reader through the RFID Application Interface (API) provided from the RFID provider and manipulates the stored data in a MySQL™ database using the MySQL Database API. The developed tracking subsystem is depicted in Figure 5-11.

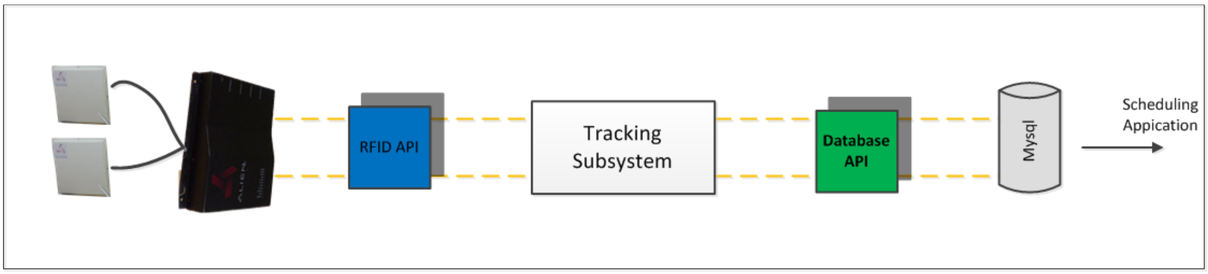


Figure 5- 11: The Developed Tracking Subsystem Infrastructure

The tracking subsystem's features include the following functions:

- *Tag registration to enable a new tag be added i.e. assign a new ID to a new vehicle*
- *Tracking vehicle status in a depot*

- Identifying an orientation of vehicles e.g. In/Out loading yard

- Monitoring progress of the tonnage delivered

- Monitoring fleet composition

The vehicle tracking subsystem display is shown in Figure 5-12.

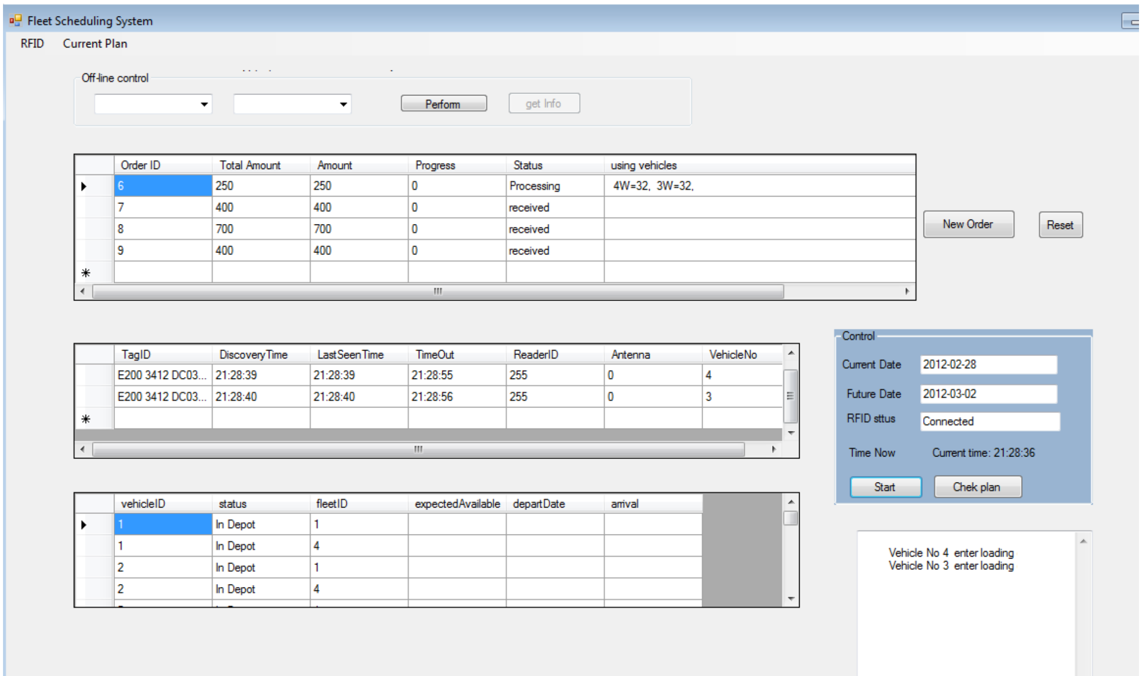


Figure 5- 12: Display of the Developed Vehicle Tracking Subsystem

2) The Scheduling Subsystem Design

The scheduling subsystem was developed to generate an optimal delivery schedule. The generated schedule suggests a fleet composition with the detailed containing tonnage of each vehicle, and its dispatch date in a certain planned period e.g. 1 week. The schedule was developed using constraint programming to optimise the allocation of subcontractors to reduce the cost when making deliveries and also satisfying a number of fundamental constraints in fleet management. The scheduling subsystem was implemented in Java and deployed in Choco, a java based constraint programming library, to solve the problem. Inputs for scheduling are retrieved from the centralised database previously used in a tracking subsystem; some of the inputs are also given by the user directly as constraints of a scheduling. The interaction of a scheduling component with other components is shown in Figure 5-13, and a display of the scheduling subsystem is as Figure 5-14.

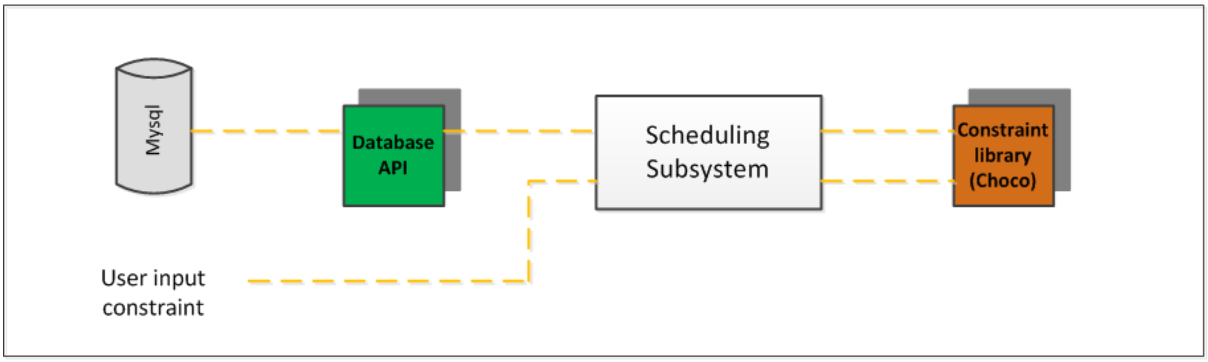


Figure 5- 13: The Scheduling Subsystem Infrastructure

The scheduling subsystem's features include the following functions:

- *Minimising a sub -contractor allocation*
- *Satisfying 8 constraints (detailed in chapter 4)*
- *Flexible number of days to be scheduled*
- *Heterogeneous capacity of vehicles*
- *Rescheduling in real-time*
- *Guaranteeing all orders to be scheduled*
- *Minimum load assignment guaranteed to improve capacity utilisation of vehicle*

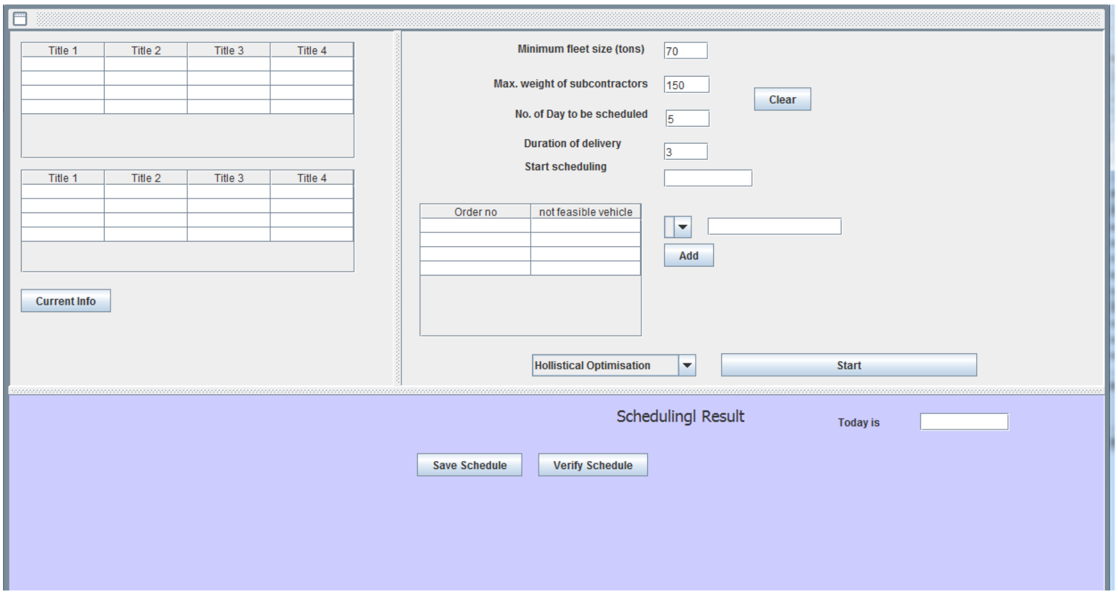


Figure 5- 14: Display of the Developed Scheduling Subsystem

5.3.4 Data Organisation Aspect

Data in the system are organised in following two ways: 1) storing data in the database and 2) storing data in the RFID tag. The data organisation are discussed as follows:

1) Database

Majority of data used to support the fleet management system are organised in a relational database system using the MySQL database. The database contains of 17 entities shown in Figure 5-15.

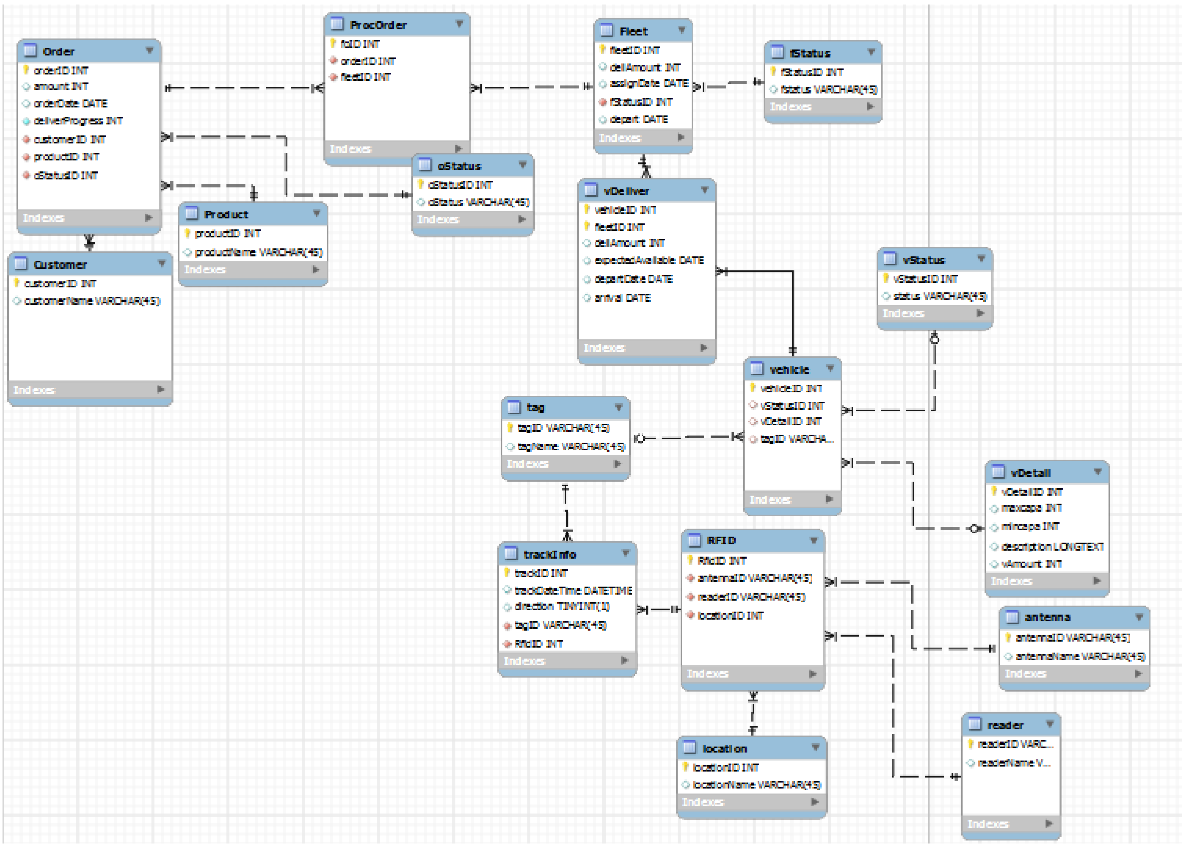


Figure 5- 15: The Database Designed for the Proposed System

The stored information is used for two purposes: 1) for answering basic routine business questions and tracking queries (such as what are the orders?, what are the progresses of orders being served?, what are the availability statuses of vehicles?, and what are the locations of vehicle in depot?); 2) for generating a schedule and the results of the schedule. The parameters for scheduling are order information (e.g. customer and order amount) and vehicle information (e.g. vehicle capacities). On one hand, the order status (the oStatusID from the entity Order) is used to query orders that are not a completed delivery, alternatively, a tag ID (tagID) is used to identify the availabilities of vehicles (vStatusID). Another type of vehicle information for scheduling is a lower bound and upper bound capacity of each vehicle this information is stored in the entity vDetail (the minCapa and maxCapa). For the identification process, the entity RFID contains reader and antenna information that can be used to track the location of a vehicle (inferred by a location where devices installed).

The results of scheduling are mainly stored in the entity Fleet associated with several tables to answer scheduling queries. The answers that the system can provide include which vehicles are members of the fleet, the tonnage contributed by each vehicle, the total tonnage that the fleet carried, the date of scheduling, the departure and the expected arrival date of fleet, the fleet status, the order that the fleet is serving, etc.

2) In-Tag Data

Each UHF tag stores 3 fields of data as shown in Figure 5-16: The first field is the vehicle ID which is used to synchronise the other data in the database discussed previously for decision making; the second field is the global Individual Asset Identifier (GIAI-96) which is associates with other systems i.e. with a GIAI-96 stored in a tag, vehicle can be tracked and identified anywhere in the global SCM (details can be found in Chapter 2); and the third field is the user data which is reserved for other identification applications e.g. storing vehicle part serial numbers for maintenance purposes. The first field has been used in this work; the second and third fields are not used, but can be used in other applications.

Vehicle ID	GIAI-96	User data

Figure 5- 16: In-Tag Data Organisation

5.3.5 Process Engineering Aspect

The process can be explained from several perspectives which are described in the following sections.

1) System State

There are two main agents in the system: order and vehicle. The relationship is the order serviced by the vehicle. The states of each agent is dynamically changed and subjected to the events of the system as discussed below:

Order

When the order is firstly introduced, it will enter a Wait state and it will stay there until a schedule is preceded. After a delivery schedule is allocated to the order, the order will either wait for a delivery in a Scheduled or transfer backward to the Wait state if it is rescheduled. Next, the schedule will be updated, based on the progress of completion. If the delivered tonnage meets the order, the order is completely served; otherwise the order is still processed in the schedule. The variation of the state of an order in the system is illustrated in Figure 5-17.

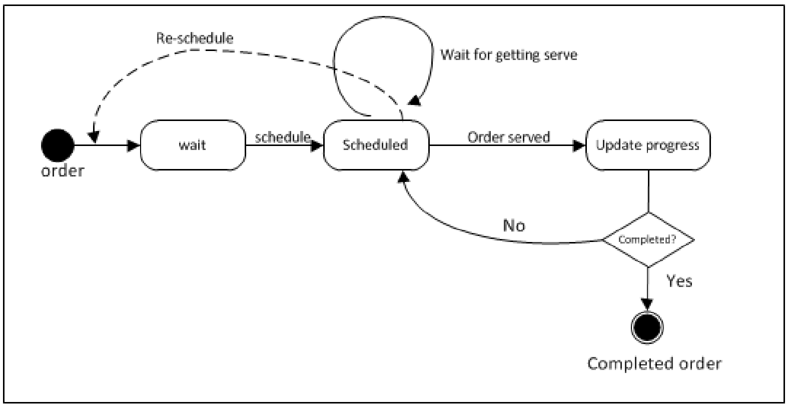


Figure 5- 17: The Variation of the State of an Order in the System

Vehicles

A vehicle is a reusable resource of the system. Whenever a vehicle is available it will have a Wait state. The state is shifted to Scheduling when the module schedule is started, which means some vehicles may be assigned for the new job. When a vehicle is assigned to load grain according to the plan, its availability state will be updated. After that, it will make a delivery and returning back to the depot waiting for a next assignment. As long as an allocated vehicle has not started loading grain, a re-allocation (rescheduling) may be applied to that vehicle which will set a vehicle state to a Wait again. Also, as this system has an assumption to simplify the problem that the vehicle requires no maintenances it will always be ready to process the next delivery, when the assigned delivery is done. The variation of the state of a vehicle in the system is illustrated in Figure 5-18.

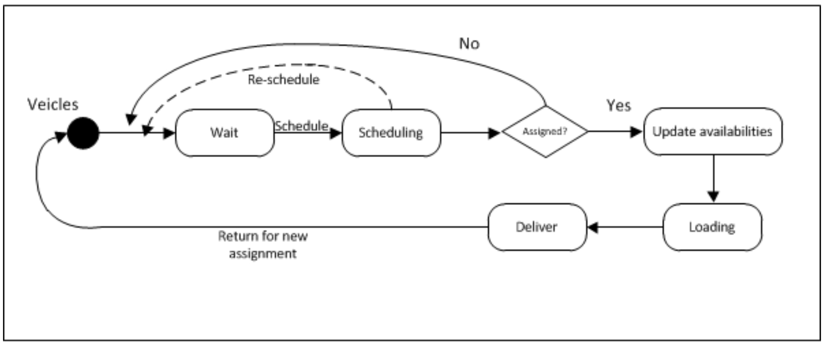


Figure 5- 18: The Variation of the State of a Vehicle in the System

2) Flow of identification

The tagged vehicle will be identified sequentially in a closed-loop manner starting from entering a loading port, leaving the loading port, leaving a depot, and returning the depot. Each identification triggers different operations to perform on the database (DB), the Output, and condition checking differently. The algorithm to demonstrate a loop of identification is presented using the pseudo code in Figure 5-19.

```
Loop: Tag Identification

    Case 1 (Enter loading yard)
          DB : vehicle status = loading(in)
              : order status = processing
      Output: Indicated order is started serving
              : Show vehicle info
              : Show assigned vehicle/tonnage → order
    Case 2 (Leave loding yard)
          DB : vehicle status = loading(out)
    Case 3 (Leave depot)
          DB: vehicle status = depot(out), departure date = current date, expected arrival = current date + delivery time)
      Output: Show vehicle info
    Case 4  (Returning depot)
         DB : vehicle status = depot(in), arrival date = current date)
          If (arrival time ≠ expected arrival time)
              Output: Schedule breaks, suggest rescheduling
         end if
         DB : Update delivery progress
     Outout: Remove assigned vehicle/tonnage → order
          If (order = delivered amount)
              DB : Order status = completed
              Output: Remove order
          end if

  End Loop
```

Figure 5- 19: Pseudo Code of Identification Process

3) Data Value Chain Process

There are two important components used for processing data in this research: RFID technology for data acquisition and a scheduler for decision making. Both elements are working associatively to build up information to support the real-time logistics decision. The interaction of these two can lead to incrementing the value of logistics information as indicated in Figure 5.20.

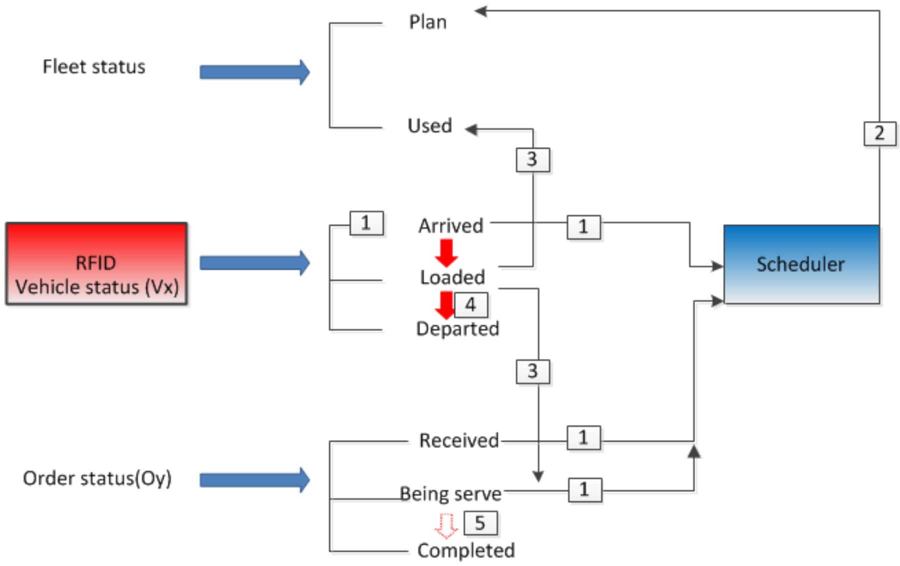


Figure 5- 20: Data Value Chain process between RFID and Scheduler

In Figure 5-20, there are three information domains: fleet, vehicle, and order which are outlined as follows:

1) the fleet status which could have value 'Plan' to indicate that a given fleet is planned, or 'Used' to indicate that this planned fleet is used for deliveries;
2) the vehicle status supported by the RFID technology which in this framework has a value 'Arrived' to indicate that the vehicle returns to the depot, 'Loaded' to indicated that the vehicle has loaded grain and ready for delivering, and 'Departed' to indicate that the vehicle is departed from the depot for delivery;
3) the order status contained 'Received' for showing a new order is received from customers, 'Being served' to indicate that an order is being served, and 'Completed' to indicate a completion of a delivery.

Attaching a RFID tag to a vehicle will make the vehicle status in the truck-yard known. From Figure 5.20, the value chain is started when the vehicle returns from a delivery to the depot. After a tag is identified, the vacancy status of a truck is updated to indicate that the vehicle is ready for a new job assignment by the scheduler. When a schedule is started, a vacancy status of the vehicle, together with any order having status not equal to 'Completed' will be inputted to the scheduler. A schedule is then generated by mapping the unfinished deliveries to generate a fleet of available vehicles. Consequently, fleet information is activated by having the fleet status as 'Planned'. The process will be held until the allocated vehicle starts the loading grain process at a loading portal. After that the fleet status is changed to 'Used', and the order status is then 'Being served'. When a vehicle leaves the depot for delivery, the vehicle status is then set to 'Depart'. Finally, a completion of a job order is verified. If there is a completion, The 'Complete' status will be assigned to the order, otherwise the entire processes are iterated.

4) Rescheduling Process

The produced schedule is used to guide the assigning and dispatching of vehicles from a depot. As long as there are no disruptions, scheduling is still applicable to use. However, in at least the following three situations, a rescheduling is required after a vehicle dispatches a depot.

- Firstly, when vehicles break down or have an accident, replacements from the available vehicles in the depot are required.
- Secondly, after the vehicles reach the destination at the customer's factory, they sometimes encounter bottleneck problems when unloading goods which subsequently causes a delay to a vehicle returning to the depot. In this situation, the rescheduling process has to be managed by the management level. For example, on each day if not every expected returning vehicle return to the depot by 12.00, the schedule will be re-scheduled.
- Finally, when there are new orders requested and the company desires to serve them immediately, a rescheduling is required to include them in a plan. The rescheduling process is shown in Figure 5-21.

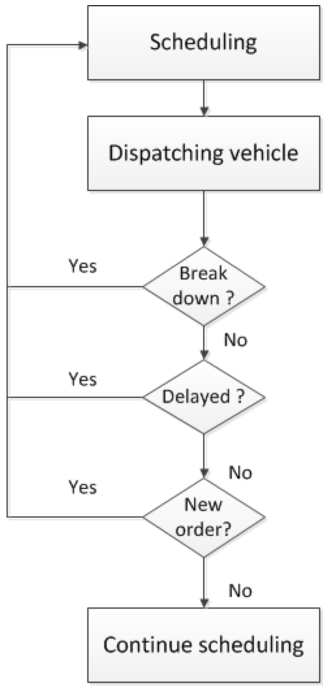


Figure 5- 21: Rescheduling Process

5.4 Phase3 - Validation and Evaluation

The validation has been conducted to ensure that the proposed system delivers correct operational logic, outcomes and flows. The system has been validated using the following two methods: 1) using the scenarios to validate the system and 2) investigating the feedback from the field study.

5.4.1 Scenario Validation

This validation aims to cross-check the coherence of using two developed subsystems and the database to generate real-time decision support for the scheduling application. The simulation demonstrates how the system can be used to tackle the following imitated business situations.

<u>Example</u>: The Company receives 4 orders (order #6, #7, #8, #9) from customers with the amount of 250,400,700,400 tons respectively. The customer who made the order #7 does not prefer a fixed-vehicle to make delivery. Each order takes 4 days to complete the delivery (3 days for delivery, and 1 day off for the drivers are required).

1) The scheduling subsystem is shown in Figure 5-22. Firstly, the software retrieves those four orders and the available vehicles by showing the minimum and maximum capacity, and the vehicle type. The basic parameters are: number of vehicles = 23, minimum fleet size = 70 tons, maximum weight allowed by hiring a subcontractor for the order = 150, number of days to be scheduled = 5 days, processing time of delivery = 3), and the fixed-vehicles are the vehicle number 1-10 (they will be not allowed to assign to order # 7).

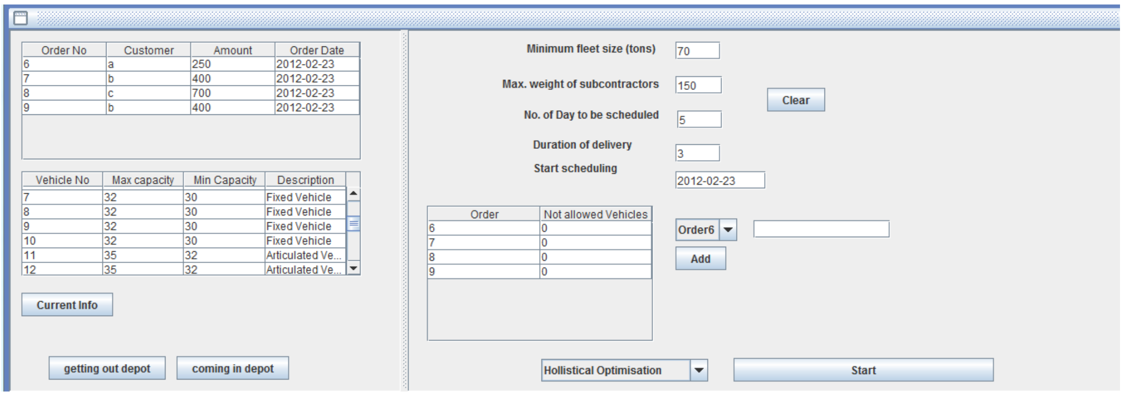


Figure 5- 22: The Input for Scheduling Software in the 1st day of scenario

The scheduling runs to produce the results shown in Table 5-5.

Table 5- 5: The results of scheduling in the 1st day of scenario

Fleet No.	Vehicle No/Weight	Order	Amount	Depart (schedule)	Day of Calendar
1	1/32,2/32,3/32,4/32,5/32,6/32,7/32	6	224	1	1
2	11/35,12/35,13/30,14/30,15/30,16/30,17/30,18/30,19/30,20/30,21/30,22/30,23/30	7	400	1	1
3	8/32,9/32,10/32	8	96	1	1
4	1/32,2/32,3/32,4/32,5/32,6/32,7/32,8/32,9/32,10/32,11/35,12/35,13/35,14/35,15/35	8	495	5	5
5	16/35,17/35,18/35,19/35,20/35,21/35,22/35,23/35	9	280	5	5

The result in Table 5-5 is interpreted: There are 5 fleets generated. Vehicles 1-7 are assigned to fleet 1, each of them will load 32 tons of grain to serve order 6 and dispatch on the day of the schedule produced. It can be seen that after the vehicles are dispatched, vehicles cannot be allocated to any order for 3 days, and the next delivery is on the 5th day where Vehicles

1-7 are set to join vehicles 8-15 in fleet 4 to serve order 8, and so on. Also, Order 6, 7,8 can be started serving immediately on the day of scheduling by fleet #1, 2, and 3 respectively, and order 9 can be served at the 5th day of this scheduling by fleet# 5. The proportion of assigning the owned vehicles and the sub-contractor for this scenario is summarised in Table 5-6. The total weight required to deliver is 1750 tons. The scheduling allocates the owned vehicles to deliver 1495 tons, and allocates the subcontractors to deliver 255 (26 tons for order 6, 109 tons for order 8, and 120 tons for order 9)

Table 5- 6: Proportion of Allocating Owned Vehicles and the Sub-Contractor in the 1st Day of Scenario

Order	Amount(tons)	Owned vehicle (tons)	Sub-contractors (tons)
6	250	224	26
7	400	400	0
8	700	591	109
9	400	280	120
Total	1750	1495	255

2) A transport manager follows the schedule to assign delivery tasks to the drivers. After that, he can use the developed tracking software to monitor the progress of a delivery in a depot. For example, Figure 5-23 indicates that 2 vehicles are identified by the reader in a loading port indicating that the vehicles are loading grain to make deliveries.

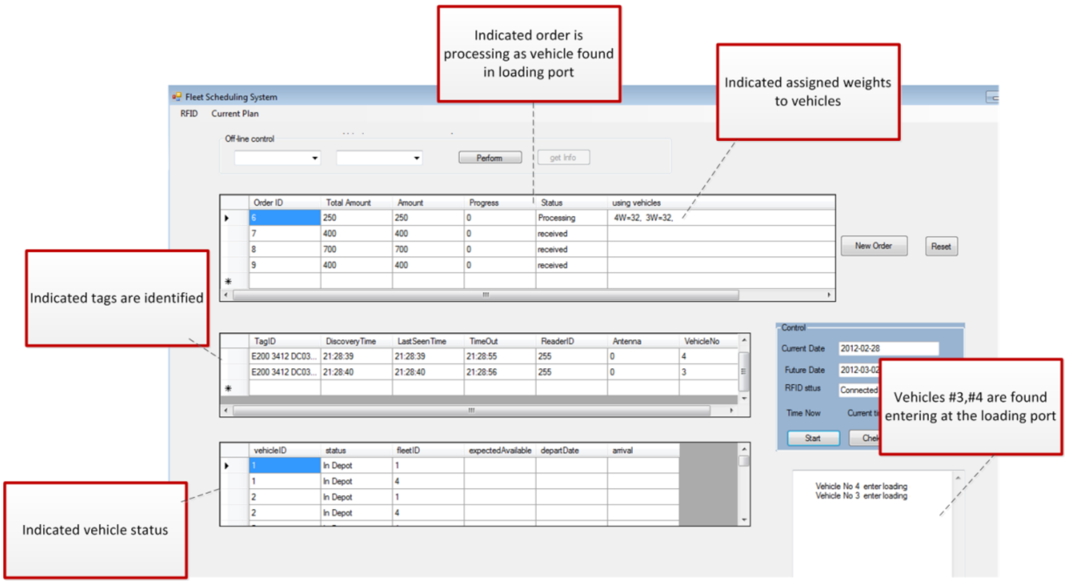


Figure 5- 23: The Use of the Developed Tracking Software to Monitor the Vehicles in the Depot

3) After the vehicles are dispatched from the depot, they are expected to receive the next identification when they return to the depot by the entrance reader. The identified date is also checked to verify that the schedule is still on the plan i.e. if the identified date is as the expected returning date, the scheduling is valid for continuing, if not i.e. the vehicle either returns earlier or later than the expected returning date, a rescheduling is required. The sooner a late returning is detected, the better performance of the real time scheduling. Instead of detecting a late returning of the vehicles when they return to the depot (which can be too late), the manager can use the system to audit an arrival of each vehicle on a daily basis to check that any vehicles are not returning contrary to the plan. In any cases where the vehicles are detected as not returning as planned, the system will prompts a message to notify that a rescheduling is required as indicated in Figure 5-24.

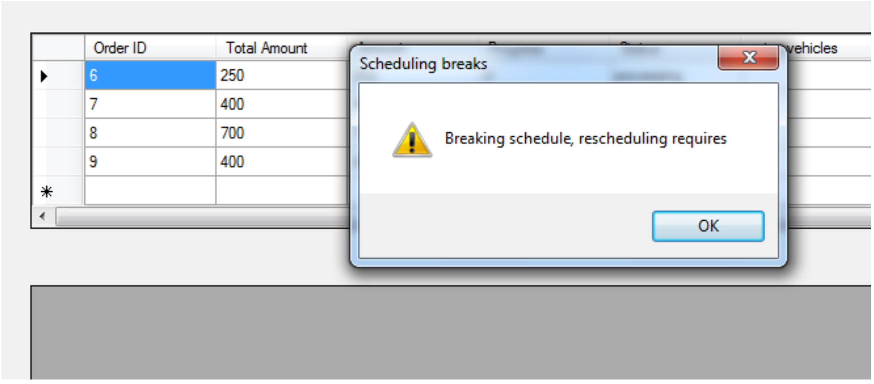


Figure 5- 24: Notification when the Schedule is Broken

On the 4th, all the dispatched fleets are supposed to return to the depot, but assuming that vehicle #3 does not, a rescheduling is required. The impacted fleets are fleet # 4 and 5. In this situation, there are 22 vehicles available, and 775 tons to be delivered further (order 8: 495, order 9: 280). On the 5th day the scheduling software proceeds to generate a new schedule. If the orders due to complete by this day as an original plan. The schedule parameter used to indicate the number of days to be scheduled shall set to 1 (number of days to be scheduled = 1), and the result of scheduling are produced as indicate in Table 5-7.

Table 5- 7: The Results of Scheduling in the 5th Day of Scenario

Fleet No.	Vehicle No/Weight	Order	Amount	Depart (schedule)	Day of Calendar
4	1/32,2/32,4/32,5/32,6/32,7/32,8/32,9/32,10/32,11/35,12/35,13/35,14/35,15/35	8	463	1	5
5	16/35,17/35,18/35,19/35,20/35,21/35,22/35,23/35	9	280	1	5

The proportion of allocating the owned vehicle and the sub-contractor in the 5th day is shown in Table 5-8. The observation is that the schedule generates similar result as the original schedule except vehicle #3 is replaced by a sub-contractor to deliver another 32 tons.

Table 5- 8: Proportion of Allocating the Owned Vehicle and the Sub-Contractor in the 5th day of the Scenario

Order	Amount(tons)	Owned vehicle (tons)	Sub-contractors (tons)
8	495	463	32
7	280	280	0
Total	775	743	32

Using scenarios to validate the integration of the system indicates that each component of the proposed system is able to corporate well to produce valid results.

5.4.2 Feedback Investigation

The feedback investigation was conducted by collecting feedback from the company on the developed system. The procedure was started by meeting the management staff of the company (referred as participants in this context) in a group; the CEO was met separately to prevent a domination of the feedback. Then, the research aims and background of the technologies e.g. RFID, computer-based scheduling, and the concept of the proposed system were explained to participant. Next, the system was also demonstrated to give opportunity for the participants to participate by asking questions, and giving inputs of parameters to verify the results. After that, the structured interviews (Appendix-2) were conducted by gathering both quantitative and qualitative feedback. Participants were asked to rate the developed prototype on four criteria: Easiness (E), Correctness(C), Benefit(B), and Implementable(I) using 5-1 scale score where 5, 4, 3, 2, 1 defined as 'Excellent', 'Good, 'Average' 'Poor', and 'Unacceptable' respectively. The following questions were used 1) "How easy do you think the system is to use?" 2)"How much does the system provide a correct result? " 3)"How much can the system provide benefits to the company?" and 4)"How practical is it to implement this system?" The following are the results of the feedback investigations:

No.	Role	Easiness	Correctness	Benefit	Implementable
1	CEO	5	5	5	4

Comments:

- The system could be improved further by balancing the workload of vehicles in a schedule such that they are utilised equally. Afterward, a policy can be set to enforce drivers to work as the schedule suggests.
- Cost and profit are the factors to consider when deciding whether the system should be transformed to a computerised system.

No.	Role	Experience	Easiness	Correctness	Benefit	Implementable
2	Backhaul Order	8 years	5	5	4	5

Comments:

The idea of the system is implementable, but it might take time to familiarise staff with the new system. Another important issue that should be considered is how the system will handle a computer failure i.e. power failure.

No.	Role	Experience	Easiness	Correctness	Benefit	Implementable
3	Dispatcher	7 years	4	3	4	5

Comments:

The concept is fair, but feel not quite convince that the system can replace humans. The suggestions are that queue constraint i.e. First Come First Serve (FCFS), shall be included as it has been because otherwise drivers may argue the schedule produces an unfair workload. Another issue that the system might not applicable to the company is the company has no high precision weighting scale when loading grain to a vehicle.

No.	Role	Experience	Easiness	Correctness	Benefit	Implementable
4	Quality Control	1 year	5	4	5	4

Comment:

No comment

No.	Role	Experience	Easiness	Correctness	Benefit	Implementable
5	Accounting	5 year	4	4	5	5

Comment:

Using computer assisted planning will improve processes by making them more systematic. However, manual operations might be required as a backup to deal with a system disruption. Also, one of the limitations is using RFID for monitoring is only allowed to track the vehicles in the depot areas.

Feedback analysis

The feedback investigation generally shows that the staff and CEO of the company are in strong agreement on the proposed methods as outlined in Table 5-9 the Median in all criteria was ranked at the maximum satisfaction, except Correctness where participants indicate that system can be improved. The advantage that the participant agreed the system is very easy to use reflects that the proposed system can improve knowledge transfer i.e. a task can be undertaken by others where the correctness of operations still can be maintained at a high level. The proposed system can clearly provide benefits to the company, and the concept is practical to implement commercially.

Table 5- 9: Overview of Feedback Investigation

						Median
Easiness	4	4	5	5	5	5
Correctness	3	4	4	5	5	4
Benefit	4	4	5	5	5	5
Implementable	4	4	5	5	5	5

Analysing the feedback of staff by responsibility showed that both CEO and staff who have different roles agreed the advantage of the proposed system as indicated in Table 5-10. The participant who has lesser agreement on the proposed system is the management who is in charge of dispatching vehicles from the depot.

Table 5- 10: Feedback by Job Responsibility

Roles	Performance Criteria				Median
CEO	4	5	5	5	5
Backhaul Order	4	5	5	5	5
Dispatcher	3	4	4	5	4
Quality Control	4	4	5	5	4.5
Accounting	4	4	5	5	4.5

It was also found that some of the feedback comments can be used to supplement and explain what the proposed system are rated. The CEO rated the proposed system with the highest score on every performance criteria except the 'Implementable'. The CEO commented that the cost-profit information is required to confirm the practicality of the proposed system, and an extra consideration on balancing vehicle workload can be integrated to make the system perfectly complete. The dispatcher ranked the Correctness of the system as average in term of satisfaction. The comment, which agreed with the CEO's, is that the constraint to balance the workload of drivers in scheduling is required to prevent comments from drivers that an unfair scheduling is produced. Also, the limitation to adopt the proposed system is the company currently does not have a high precision weight scale yet. The accountant, who also rated the correctness of the system four of five, commented that the proposed system should be required to enable the vehicle to be monitored outside company premises. Also another issue is the 'Easiness' in which the system might be required to operate manually as a backup solution. However, he emphasised the benefit of the system that the proposed system can improve the effectiveness of operations.

In addition, there are two issues that are commonly identified by participant to improve the proposed system 1) the workload balancing constraint shall be considered and 2) the efficiency backup solution might be required to handle failure of the computerised system.

5.4.3 Process Flow Evaluation

The evaluation was also conducted to measure how the proposed system can enhance the process of scheduling by comparing the time required to be spent to complete each process of the current operation and the proposed system.

The overview routine of the scheduling process is indicated in Figure 5-25. When an order is received, the Transport Department is responsible for the entire delivery process. They check the availability of the vehicles in the yard, as well as a stockpile of the grain stored in the warehouses. After that, they make a daily plan (there is no plan in advance e.g. weekly and monthly) by allocating available vehicles to tonnage of grain to be delivered. Next, the Transport Department will hand in a delivery form to the drivers by indicating the product type and delivery location. When the delivery is completed, vehicles return to the depot to queue for the next delivery assignment. If there are any incidents so that the vehicle cannot continue a journey e.g. break down, the next vehicle in the queue will be sent as a replacement.

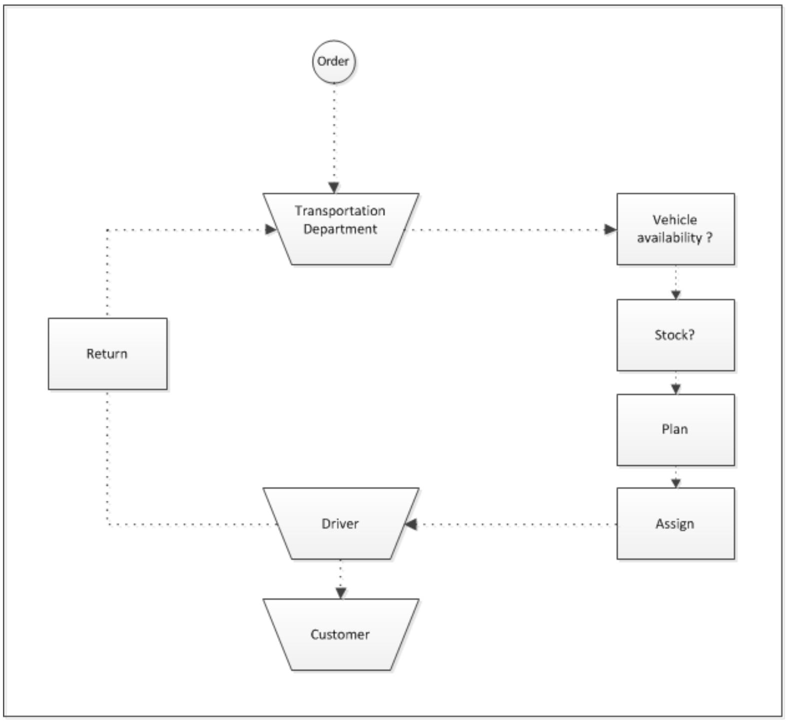


Figure 5- 25: Scheduling Routine of the Case Study

The interview was conducted with the Transport Department to determine the time spent on each of the activities of the current fleet scheduling system. This information compared with the times required from the proposed system. Most of the activities in the proposed system are computerised, except two activities; stock checking and vehicle assignment, which still require manual operations. The comparison results between the current system and the proposed system are indicated in Table 5-11.

Table 5- 11: The Comparison Results between the Current System and the Proposed System

Task	Current system	Proposed system
Checking availability of vehicle	-Checking availabilities of vehicles from paperwork (or in yard). -Takes 2-5 minutes	-Database query -Nearly real time speed
Stock Checking	-Manual check -Takes 10-15 minutes	-Manual check -Takes 10-15 minutes
Scheduling	-Dispatcher composting fleet based on knowledge and experience. -Daily schedule -Takes 1-5 minutes	- Generated by computer. - Weekly schedule -Takes 2 second
Assigning drivers	-Manual assign - Takes 5-10 minutes	- Manual assign -Takes 5-10 minutes
Returning vehicles	-Driver manually report to the company - Take 10-15minutes	RFID identify vehicle automatically -Nearly real time speed
Total Time	28 - 50 minutes	15-25 minutes

The work flow evaluation indicates that the proposed system can reduce the time spent for administration and planning significantly. Three out of the five manual steps can be improved by applying the computerised system which can reduce the total time spent to approximately 15-25 minutes. Also, another advantage of the proposed method is when rescheduling is required regarding a delay, the system will recognise it in real time, and a new schedule can be generated shortly afterward. In addition to the reduction of the operational time (50 % total time saving of the logistics cycle), the system provides a number of extra benefits over the manual scheduling, e.g., producing a multi-period plan (e.g. weekly plan) instead of a daily plan, improving 'ease of use' of the system which can lead to an improvement in knowledge transfer, and preventing a driver conspiracy etc.

5.5 System Transformations

It can be seen from the validations that the proposed system is able to improve the current agricultural fleet logistics operation when the information system is transformed. Also, there are opportunities for the proposed system to be steadily improved further. Figure 5-26 indicates the proposed three phases of the information transformation under the consideration of information level classification (Turban et al., 2007). The first phase is the current operation of the company. Most of the administrations in the depot are based on human direct communication, paperwork is produced excessively, and there is only usage of basic IT such as Microsoft Excel, Microsoft Word, Calculator and Calendar for personal and productivity purposes. The second phase is the proposed system of this research. Manual operations are steadily replaced by a computerised system and IT contributes to generate far better advanced IS. RFID will be used to build an automatic transition processing system for vehicles management, and data will be used to input a fleet scheduling system to generate an optimal decision. The decision support application in this phase of IS can be seen as a 'Pull' system which means the application is operated when a decision-maker makes a request The deployed infrastructure in this phase acts as a core system for further expansion in the next phase. The final phase is the system expansion. With the deployed technologies in the second phase e.g. GPS, RFID and database; it will enable the system to be retrofitted to achieve higher levels of IS. For example, the system can be expanded to achieve the enterprise information system, with integrated applications building on top of the proposed system. The system even has the potential to achieve inter-organisation, global, or very large system level as proposed GIAI-96 code in a RFID tag will allow the system to be synchronised with other systems.

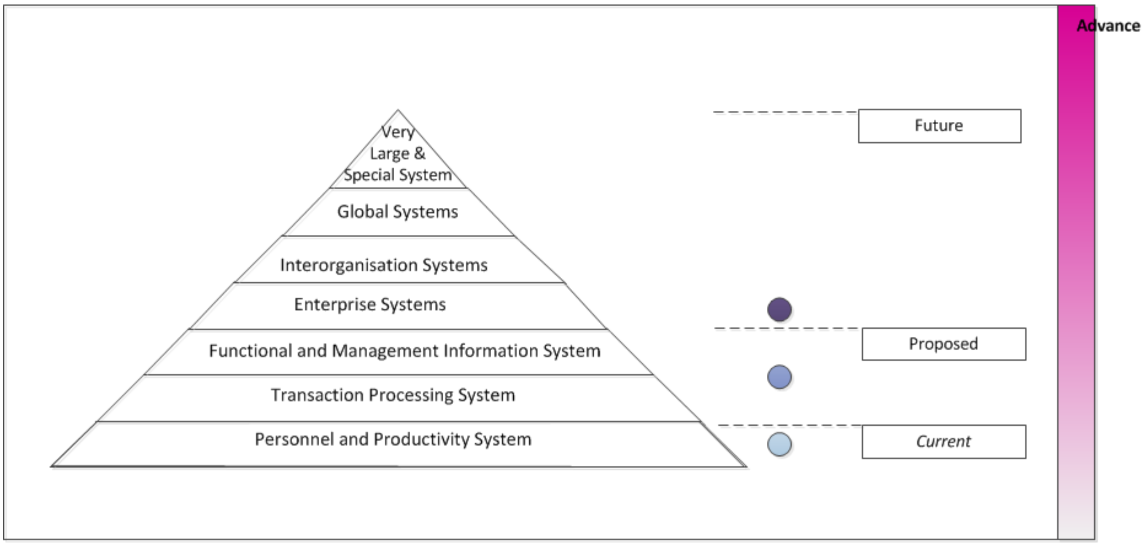


Figure 5- 26: Information Level Classification and the Proposed System

Table 5.12 summarises the impacts of system transformation in management, information and technologies aspects. In management, all decisions of the current system are made by humans. This indicates that the efficiency of the system depends highly on experience and management and decision-making skills of managers. It also implies that the management task is difficult to be undertaken by other staff e.g. when an experienced manager leaves. Management of the proposed system will be initially supported by a computerised system in the fleet management. Optimal scheduling can then be generated by computerised systems. Ultimately, in the future the system can be completely operated by an IT system, and the manager may only be required to exercise supervision on exceptional decisions. In the current informational aspect, the system is paper based and requires direct human communications to operate the system. The proposed system pioneers the storage of digital data in a database for certain applications, it can be retrieved for decision making or can proceed to produce optimal decisions automatically. Information in this phase is a 'Pull' basis which means it is called to support human decisions. The future system - a database can be expanded to support all decisions in an integrated way, and a 'Push' basis can be implemented to improve the automation of the system. In terms of technology, the current system only utilises basic technologies to support the individual tasks. The proposed and the future systems are retrofitting in ways that maximise using existing technologies and finally integrating them together.

Table 5- 12: The System Transformation

Phase	Management	Information	Technologies
1: Current system	highly depend on human decision	-paper bases -requires extremely direct communication	- office automation tools + GPS
2: Proposed system	IT support human decision fleet management	- Pioneering a computerised decision support system in fleet management applications -Pull IS	office automation tools +RFID + Database+ Optimisation
3: Future system	- IT play more role -Ultimately IT operate the logistics system under human supervision	- Computerised systems Holistic information service - Push/Pull IS	office automation tools +RFID + GPS +Optimisation+ Enterprise database

The information system hosts holistic services for several applications in transport logistics management. Those retrofitting are outlined as follows.

1) Constructing an integrated system

The previous investigation found that one of the inefficiencies of the system is caused by a lack of information sharing. A centralised database can be built to support each stakeholder giving adequate information for the decision making. Also, the integrity of data can be guaranteed as stakeholder access the same source of information as transactions occur. Not only can information supply decision makers in 'Pull' manner, but the 'Push' system can be built also for further effectiveness by embedding Artificial Intelligence (AI) mechanisms to monitor the processes and automatically respond to human or other AI to take appropriate actions. For example, the system could suggest the buy-in and sold-out product volume to managers to optimise a stock level. When orders are received, a scheduling system proceeds automatically by considering stock level information. This concept is closely related to the concept of the 'Internet of Things (IOT)' which is discussed in Chapter 6 on future work.

The system can also be considered as the part of the Customer Relationship Management (CRM). This would include customers in the network allowing them to track the deliveries throughout the process. The customer might want to implement an E-procurement as part of their upstream supply chain of the customer which can improve sales. An authorisation will also require appropriate filtering information for different users of the system. The concept of the integrated system is shown in Figure 5-27.

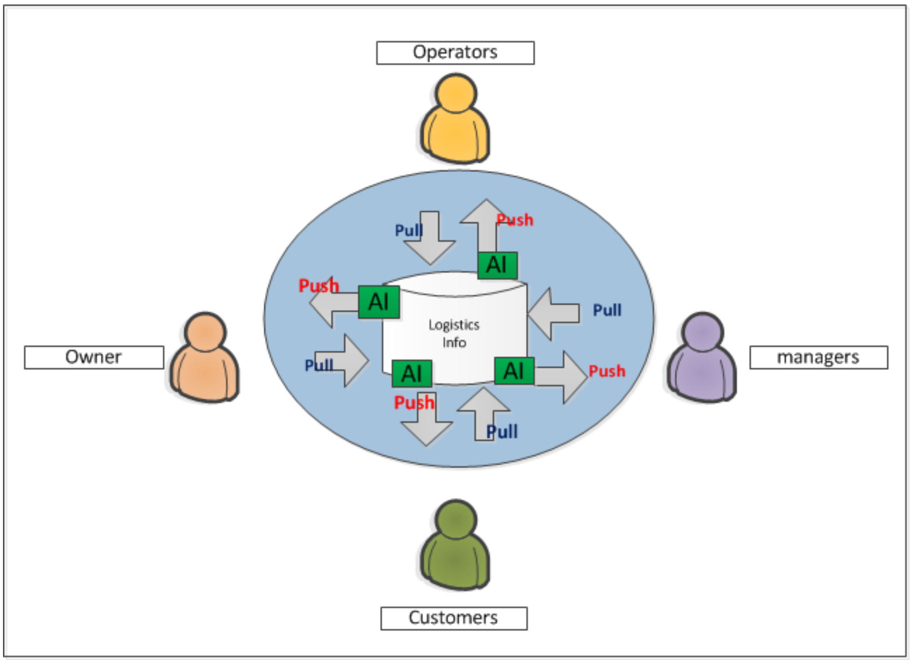


Figure 5- 27: An Integrated System Concept

2) Improving part tracking and maintenance process

RFID can also be applied for improving the maintenance operations and detecting if a vehicle's parts are lost. One of the critical issues that the company encounters is that parts of vehicles are stolen by drivers i.e. drivers replace parts with second-hand ones. To verify the originality of the parts, a serial number for each part of the vehicle can be stored on a database, either using a tag ID to make queries, or a serial number can be stored directly in a tag and using a handheld reader to identify them when required. The concept of extending the system for the maintenance operation is shown in Figure 5-28.

Figure 5- 28: Application of an RFID technology for Improving Maintenance Operation

RFID can also improve the maintenance process by enabling automatic notification. For example, when maintenances are recorded e.g. tyre, battery replacement, the next cycle of maintenance these parts can then be estimated. This would provide pre-planned maintenance as soon as a part is required to extend the longevity of the vehicle, and can improve safety of delivery and breakdown.

3) Asset monitoring

Apart from the trucks, the company also owns other vehicles e.g. tractors and excavators working in the premises. RFID can be used to monitor them to prevent loss, to verify the quantities of them, or to check for the availability of a specific vehicle in a depot. The concept of applying RFID technology for an asset monitoring application is shown in Figure 5-29.

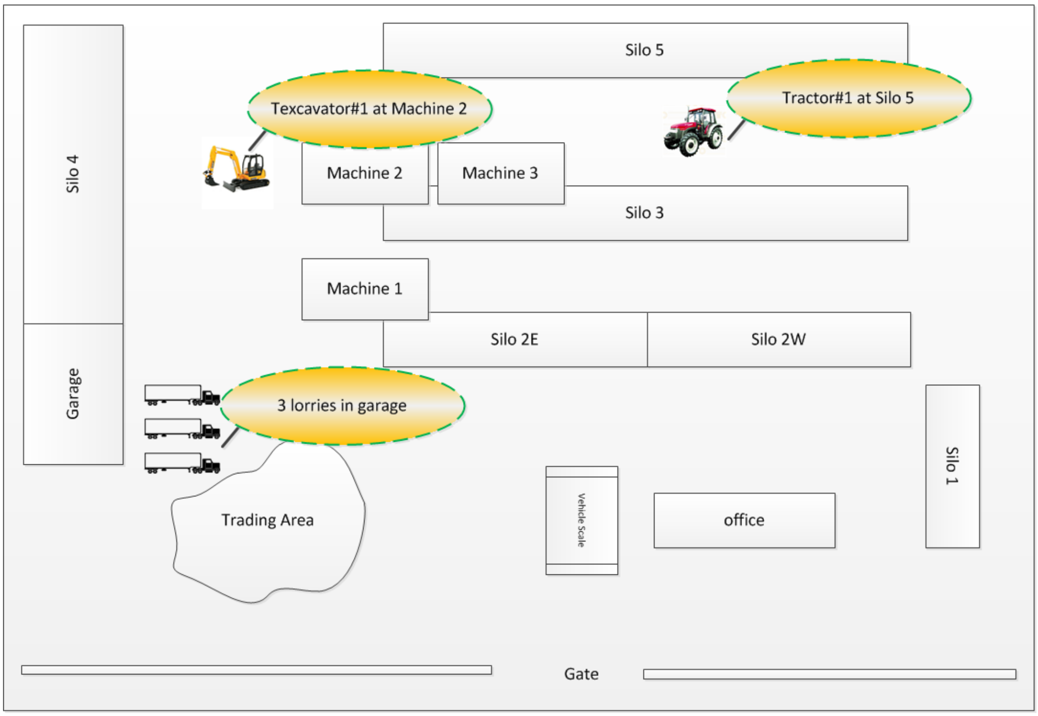


Figure 5- 29: Application of an RFID technology for Asset Monitoring

4) Telemetric management

Currently, GPS has been used for monitoring the delivery of a vehicle. With RFID integration, the delivery monitoring process can be enhanced as the monitoring can be started from the internal process in the depot as RFID can pinpoint a current location of material/product. This will benefit to both company administrators who can visualise all processes as well as monitoring vehicles throughout their supply chain, and customers who can check the progress of their orders in real time. The concept of integrated telemetric using RFID and GPS is indicated in Figure 5-30.

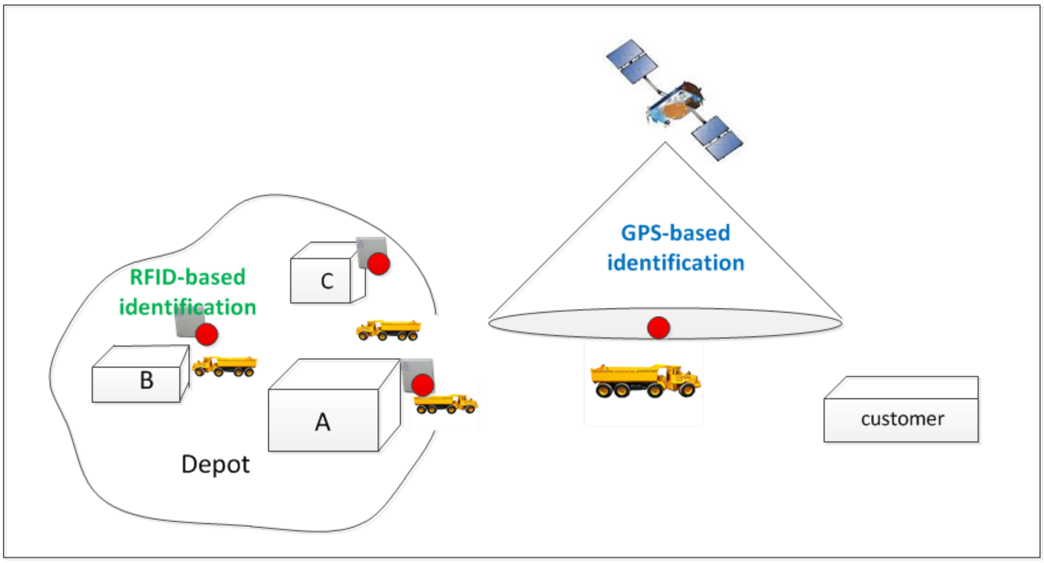


Figure 5- 30: The Concept of Integrated Telemetric Using RFID and GPS

5.6 Summary

The chapter discusses the system development in three phases. In the first phase, the research conducted a problem survey to investigate the company background and existing technology, investigating problems encountered and identifying the focus of the developing system. The second phase is the implementation phase. The chapter discussed the design and implementation in four aspects which are hardware (hardware installation), software (two subsystems: tracking and scheduling, and their features), data organisation (data media and how to get them organised), and process engineering (an interaction between each components and workflows of the new system). The final phase of system development is the validation and evaluation which are conducted in 3 ways. 1) Scenario is used to test integrity of each component. 2) The feedback towards the developed system is taken from the company and the results indicated that the proposed system is logically applicable to the case study problem. However further developments are required to make them ready for a practical usage. 3) A simple evaluation on the flow of the system was benchmarked. It was found that the proposed system can improve the planning process significantly. Finally the chapter discussed a system expansion by showing the number of possible applications can be built on top of this research such as the integrated system, part tracking and maintenance management, asset management and telemetric management.

Chapter 6

Conclusion and Future Research

6.1. Introduction

The discussion in this chapter involves revisiting the identified aims and objectives with the intention to discuss the research domain and processes involved and a summary of the contribution is discussed. Limitations and lessons learnt are also included to improve future research. The future work is to tackle some of the limitations of this research, and for identifying a research direction that can be focused on in the future.

6.2 Revisiting the Objectives

This research aims to develop a realistic solution to enhance the efficiency of transport logistics operations in agricultural businesses in Thailand using two important technologies: RFID technology and the Constraint Programming optimisation-based method. Revisiting the objective identified at the start of the study defined in Chapter 1.3 is to assess the completion of the study. The objectives revisiting are outlined as follows:

"To review the transport logistics problems in general, and the specific challenges faced in Thailand in particular"

A review has been conducted in Chapter 2 to indicate the significance of transportation in the logistics process. For example, transportation is founded in accountancy because of the large cost of the logistics. Road transportation is found to be the most used transportation method globally as well as in Thailand compared to other modes available i.e. sea, air, rail and pipeline. Road are used 45.6 %, 75 %, 72%, and 83.8% in EU-27, U.S.A., China, and Thailand respectively. The literature survey of the logistics in Thailand indicates that the country encounter some inefficiency issues compared to several countries. For instance, Thailand was ranked by World Bank in 39th position for logistics competency. Also, the logistics cost in Thailand reached 11% of the Gross Domestic Product (GDP) of the country, while in Japan, Canada, U.S.A. the logistics cost are 5.1 %, 5.5 %, and 8.8 % correspondingly. The top three transportation problems in Thailand are 1) Empty Backhaul 2) Late delivery, and 3) Vehicle shortage.

"To investigate the current practice of the case study company through field studies"

The case study investigation is mostly discussed in Chapter 5. Semi-structured interviews are conducted to obtain the challenging issues, and background. This also allows process observation to provide clearly an understanding of the transport logistics operations of the case study company. The field study identified several problems the company encountered in both technical issues, such as empty backhaul, petrol shrinkage, and employee loyalty, and management issues such as, no automatic workflow, optimal decision cannot be guarantee and difficulty in knowledge transfer. Fleet scheduling optimisation is the focus of the study because the problem involved several issues identified previously; hence it can greatly impact on the overall effectiveness if the problem can be resolved. The problem specification is to solve a class of fleet scheduling problems in which the company requires to maximise the allocation of owned vehicles where hired vehicles are available. A soft constraint and a number of hard constraints are investigated. The outcomes of the studies are used to formulate the Constraint Programming-based problem model as identified in Chapter 4.

"To investigate the RFID technology and develop a lab-based RFID tracking system for transport applications."

The general background of the RFID technology is outlined in Chapter 2, and the particular UHF-RFID system adopted is reviewed in Chapter 3. Chapter 2 discusses RFID technology using several frequencies, related the background i.e. components and standards, and various applications are outlined including general applications (e.g. a zoo application, healthcare application, sushi restaurant application, and a daily farm application) and logistics management application (e.g. customise manufacturing, order-picking in warehouse, shelf replenishment in a retail store, and reverse logistics management). The uses of RFID in logistics transportation management involved the Waste Bin Collection, Monitoring Cold Food Transportation, Traffic Management, Container Security, and Context Awareness for Fleet management. The research focuses on the improvement of RFID technology and investigates three areas: 1) improving tag e.g. a tag using for drinking water bottle 2) improving reader e.g. an energy saving reader and 3) improving security e.g. a security for multiple readers. RFID is compared to the other Automatic Identification technologies such as Barcode, Global Positioning System and License-Plate-Recognition technologies.

Chapter 3 discusses the development of a prototype system for vehicle tracking using Ultra High Frequency RFID technology. The physics of Radio Frequency is investigated; hardware procurement is discussed on tag copper pattern towards suitability of vehicle tracking application and permitted frequency in each country. The Middleware development process focuses on the extra requirements of RFID Middleware applied for Vehicle Tracking are : 1) The ability to handle stream data to detect the first discovery time, and 2) The ability to discriminate direction of identification. The former issue is solved by using a filtering algorithm and the latter is tackled using the rule 'an inverse of the last known orientation is the current orientation'.

"To conduct the laboratory-based experimentations to identify the good configuration to be applied in the case study"

In Chapter 3, the laboratory-based experiments are used to measure the impact of the working environment and system configuration. Two experiments are conducted 1) an experiment to evaluate the indoor effect and 2) an experiment to evaluate the ability of tag to be identified in various position. The finding shows the system is impacted upon by indoor effects, i.e. implemented system in an indoor environment produced fluctuating results at most distances and the position of identification relates to the identification performance i.e. the different height configuration of the tag produced scattered results for the same reader setup at each distance. These findings can provide benefits to a practical system setup for the vehicle identification application.

"To study the Constraint Programming (CP), and to find problem representation of CP for the case study problem"

The general reviews of CP are outlined in Chapter 2. CP concepts are discussed including a classification of constraints into different schemes i.e. Unary vs. Binary, and Hard Constraints vs. Soft Constraints. CP classification is primary classified as Constraint Satisfaction Problem (CSP) which includes using CP to solve feasible problems, and Constraint Satisfaction Optimisation Problem (CSOP) which includes using CP to solve optimisation problems. Several types of algorithms are identified for solving Constraint problems i.e. systematics search, local search, and Branch and Bound (B&B) which is suitable for solving a CSOP. It is found that several CP solvers introduced including ILog, Choco, ECLiPSe, Mozart, Comet, etc. They are found to solve several scheduling applications successfully such as Sport, Healthcare, Transportation, Manufacturing, Maintenance, Education, and IT resources. This research adopted the Choco solver to solve a class of logistics transportation problem.

In Chapter 4, the using of CP for tackling real world operational problems is studied. CP is used to model two problems. A Nurse Rostering Problem is formulated for CP as an example, and then the Transportation Logistics Problem obtained from the case study company is concentrated. CP is used to model the problem into formal forms in term of the variables, domains, and constraints. The objective function of the problem is to minimise the soft constraint, an allocation of subcontractors. There are 8 hard constraints defined including 1) minimum/maximum tonnage of vehicles, 2) fleet size, 3) owned vehicle has to be allocated 4) every order must be served and subcontractors can be used 5) no vehicle reassigned during delivery 6) fleet members are not static assigned 7) some vehicles are not available for some orders and 8) an order has to be served in full amount. Chapter 4 also discuss the advantages of CP over other methods.

"To develop a CP-based system to provide the decision support in transport logistics management"

Chapter 4 outlines a solution to model the problem, and an implementation is conducted to tackle the problem further using a constraint solver. This research adopts Choco, constraint java library, to solve the problem. As the Choco implemented B&B algorithm, search parameter are also need to be explored for the best strategy through the experiment. It is found that two strategies in Choco can equally produce a good answer, which is: (MinDomain/DecreasingDomain), and (MinDomain/ MaxVal). Further, the developed system is evaluated for validity in different scenarios, and it was found that the developed system produced valid results. The mechanisms of problem solving are also investigated and it is shown that when an order is incremented the variables and the constraints of the system increase massively, while an expansion of node and backtracking times are not relatively affected, and when the problem is 'over-constrained', a solution cannot be produced.

"To investigate the holistic design of the integrated RFID-CP-based scheduling of the intelligent transport logistics system"

Before a prototype can be developed, a system design and architecture is required. Chapter 5 describes the design process for the development of an integrated RFID-CP-based scheduling system. The hardware aspect is discussed for the installation of RFID technology to use in the case study. The software aspect is outlined in Chapter 5 and the implementation of two sub-systems which are 1) The Vehicle Tracking developed by VB.Net and 2) The CP scheduling developed by Java. In data organisation aspects, the developed system involves storing data in two sources which are 1) the database consisted of 17 data entities 2) In-Tag data consisted of 3 field: Vehicle ID for associating with the database,GIAI-96 for standard adoption, and User data for system expansion. In addition, several process engineering perspectives are discussed such as System State, Flow of Identification, Data Value Chain Process and Rescheduling Process.

"To develop a laboratory prototype of a real time decision support system for the transport logistics system for the case study"

The development of the RFID vehicle tracking system and the CP for fleet scheduling are integrated and discussed in Chapter 5. For instance, the vehicle identification data from RFID technology are used to indicate the availability of vehicles in a depot, and then they can be used as the inputs of the scheduling system to assign loading to the vehicles.

"To validate and evaluate the proposed method"

The studies in Chapter 5 indicate a validation and evaluation of the proposed system. The scenario validation is used to test the collaborative working of two components: RFID tracking system and CP-based scheduling. The feedbacks are also collected from the case study company using structured interviews to investigate whether the proposed method has enough validity and justification from the management staff and CEO of the company. Feedback is obtained by quantifying opinion of the interviewee on a developed system from several criteria (including Easiness, Correctness, Benefit, and Implementable), together with qualitative opinion particularly on how to improve the system further. The staff and CEO of the company are in strong agreement about the proposed methods i.e. all criteria are ranked at the maximum satisfaction, except 'Correctness' where participants indicate that the system can be improved. The advantage that the participants agreed that the system is very easy to use reflects the proposed system can improve the knowledge transfer i.e. task can be undertaken by others where the correctness of operations can still maintained at the high level. There are two suggestions that are commonly identified by participants to improve the proposed system 1) the workload balancing constraint shall be considered and 2) the efficiency backup solution might require to handle the failure of the computerised system. In addition, the study evaluates the improvement of the system in term of the time reduction in transport management process.

6.3 Topology of Contribution

The topology of contribution is a discussed from contributions roles of this research as showing in Figure 6-1.

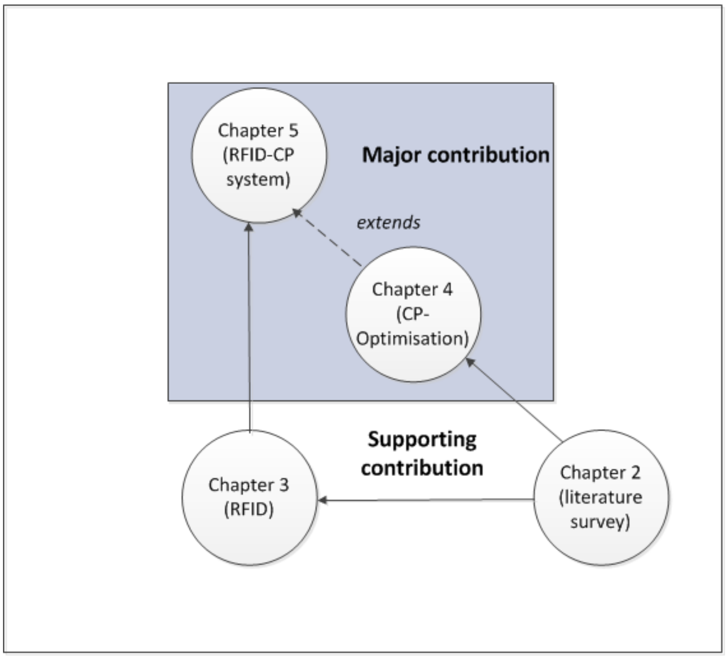


Figure 6- 1: Contribution Topology of the Study

The contributions are categorised as the major contribution and supporting contribution. The major contribution is defined based on the novelty of the research, and the supporting contribution is to support others to achieve the goal. The major contribution of this research is outlined in Chapter 4 where the Constraint Programming (CP) is used to solve combination of fleet composition problem and scheduling problem. The novelty and advantage of the method is that constraints can be imposed not only at vehicle level, but also at fleet level i.e. total tonnage of fleet require to meet minimum weight and fleet member require dynamic allocation. The key word 'extends' is using in this context to indicate that the contribution outcome in Chapter 4 can lead to the contribution of Chapter 5. For instance, while the schedule developed in Chapter 4 is Off-line, the schedule in Chapter 5 is On-line where RFID is used to capture real-time data, and can enable rescheduling. The contribution of Chapter 2 and Chapter 3 are the supporting contributions. For example, in order to develop the real-time CP-scheduling using RFID technology as discussed in Chapter 5, certain issues of RFID deploy are required resolving. Similarly, the contribution of Chapter 2 provides solid background of conducting research in Chapter 3 and Chapter 4.

6.4 Research Limitation and Lesson Learnt

Due to the constraints i.e. PhD time constraint and resource constraints, there are some unsolved problems remaining, these can be seen as limitations of the research. Each step of the study has the following limitations outlined as follows:

1) Vehicle tracking system development

The developed tracking system was only tested in laboratory, and not on a real life scale because of the financial and time constraints. The real-life test will require vehicles, depot gates, a large depot space, and several management staff, but this would lead to stronger conclusion on the usability of the developed system.

2) CP-based Scheduling development

The research applies an embedded Branch and Bound (B&B) algorithm in Choco solving constraint based scheduling. To improve practicality in producing solution which is fast enough for decision support, a simple solution using a timer to limit the search space in B&B is used. However, this may not guarantee that the search returns optimal or even suboptimal solutions (but feasible and good solutions). A better but more complicate solution is to either develop a heuristics function for a branching function in B&B to make a search perform more intelligently or try other search algorithms e.g. Evolutionary Algorithms (such as Genetics Algorithms, Simulated Annealing, and Ant Colony Optimisation algorithm) which may improve the performance of the scheduling.

The modelling of CP of the case study can also be enhanced by adding more constraints to the problem. For instance, the field validation study indicates that the company could suggest including the constraint to balance the workload of driver such that task assignments can be determined for fairness. To achieve this the problem might need to involve other class of problems e.g. weighted constraint satisfaction optimisation problem (Rossi et al., 2008), or multi-objective optimisation problem (Marler and Arora, 2004).

3) An integrated RFID and CP-based scheduling system for the case study

The integration validation of RFID and CP is conducted using scenarios and the tests are laboratory-based validations. A real implementation, i.e. using RFID technology to track vehicles and a computer-based fleet scheduling to produce and assign logistic jobs, for a period of time at the company environment would confirm the validity of the proposed approach. However, this requires a very high degree of cooperation with the company and is beyond the scope of the thesis.

4) Validation process

The validation process could be improved. A more advanced quantitative data analysis method can be used to measure the effectiveness of the proposed system. For example, a simulation study could be used to measure a performance of the proposed method against manual scheduling. However, currently the availability of scheduling data from the company is limited (as the planning is manual based), and the developed CP-based scheduling need to be deployed at the depot to collect data. Therefore, the use of simulation for validation is difficult in the current situations.

Reflecting on the entire process of conducting this PhD research, some lessons have been learnt and can be identified to help improve the productivities and qualities of future research and outlined as follows:

1) Learning from conducting research with emerging technology

Aspect of this research involves an investigation of RFID technology. When the research was initiated in September 2007, the technology was an emerging identification technology. The original intention was to claim a research contribution of that investigation, but the technology is moving fast, and the cost is reducing and is becoming less complicated. RFID became a mainstream technology in business and most of the application aspects of RFID investigation have been researched. Research that is depending on technology needs to be completed quickly. Also another pitfall when doing research on emerging technology is at first glance it seemed a number of issues to be investigated, without limiting the scope of, the investigation can take longer than it should.

2) Starting implementation much earlier

The implementation of the research should have started earlier. The improving of implementation (e.g. Algorithm development) can be endless process. The earlier the implementation can start means that the more times the development can be iteratively improved.

3) Using reference tool to manage the references

A referencing tool can facilitate organising a list of reference; it should have been used at the start of the research.

6.5 Future Research

Future research can help to resolve the research limitations identified in Chapter 6.4 Also, several research directions can be expanded as outlined follows:

1) Real time sensor focused

In this research RFID technology is adopted, and the literature review in Chapter 6.2.3 indicated there are other powerful identification technologies including 2D Barcode, 3D-Barcode, GPS, Surveillance camera, etc. These technologies hold some advantages over the other in some certain aspects as shown in Table 2-5. The future work of this focus can be application aspects or improved performance/or resolving the limitation of the technology themselves.

2) Constraint programming focused

Constraint Programming has been validated as a successful method for solving complicated real-life problems as shown in this thesis and other literature outlined in Table 2-6. The learning experiences of using CP to solve the problem from this study can be applied to solve similar problems in other domains in the future. With the advantage of using the experienced technique (i.e. CP), problem modelling and solving can be done more easily.

3) Algorithms focused

The B&B algorithm is the main algorithm used in this study. Future studies of the algorithm should focus on developing a heuristics search to enhance the performance of B&B , or focusing the research on the study of other search algorithms (i.e. for other intelligent applications) are also under consideration.

4) RFID and GPS enhancing logistics processed focused

As discussed, an RFID-based system expansion in Chapter 5 means that the future work can be involved in enhancing a using of RFID technology to improve efficiency for logistics purpose which can include a constructing an integrated system, an improved part tracking and maintenance process, an asset monitoring, and a telemetric management. Also a GPS tracking system (Chapter 5.2.3) can be installed to monitor company vehicles using a system such as 'Onetrack' which can convey information in real time regarding deliveries to customers.

5) Simulation focused

Another possibility of expanding the research direction is the studying of the use of a simulation technique to support 'what-If' in logistics decision making. The study can also involve analysing operational activities to detect inefficiencies in logistics management, or using a simulation to validate the proposed optimisation techniques.

6) New Research Paradigm: Internet of Things (IOT) focused

Currently another emerging paradigm in the RFID research society is the 'Internet of Things (IoT)' which is further steps for using RFID technology for tracking or tracing objects. The conceptual idea of the IoT is unifying every real world object under a defined infrastructure such that the objects can control and monitoring the state of other objects. The discussion of the IoT concept in agricultural logistics has also been found recently such as the study by (Weimei, 2011).

Based on this research, the system can be enhanced using a combination of RFID and GPS technologies, and other sensor technologies which would allow monitoring of the trucks movement over the entire route. The RFID services could also be expanded (e.g. part tracking, holistic logistical services, asset monitoring, etc.) and integrated into the current system. This would need to be evaluated to assess operational improvement.

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APPENDIX-1

Approval Letter

Peuchpol Suvanabhum Co., Ltd

133 Moo 9 Maesot-MaeRamat RD
Mae Pa, Maesot, Tak, 63110

11 September 2009

TO WHOM IT MAY CONCERN

This is to confirm that Peuchpol Suvanabhum Co., Ltd, Thailand is collaborating with Mr.Noppon Choosri of the College of Arts Media and Technology, Chiangmai University, Thailand. The work involves a research project to improve our operational performances as a part of his PhD study at the Faculty of Computing, Engineering and Technology at Staffordshire University, U.K. We will kindly support Mr. Noppon Choosri while he is conducting his field study surveys at our company.

ห้างหุ้นส่วนจำกัด พืชผลสุวรรณภูมิ

(MR. RERNGCHAI SUWAN)
Managing Director
Peuchpol Suvanabhum Co., Ltd

APPENDIX-2

System Validation

Participant information:

Role in the company………………..

Experiences…………………

Please rate (1-5) on the following questions. When 5, 4, 3, 2, 1 defined as ‘Excellent’, ’Good’, ‘Average’ ’Poor’, and ‘Unacceptable’

1) How do you think the system is easy to use? ………………
2) How much the system provides correct result? ....
3) How much the system can provide benefits to the company? ....
4) How much practicability to implement this system? …………….

Opinion on the system

(How do you think about the system in general?/ What can be improved ?)

Comments:……
………
………
………
………