DESIGNING A DOCUMENT DELIVERY SYSTEM FOR UCF'S INTERLIBRARY LOAN DEPARTMENT

by

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B.E. Sardar Patel University, 2002

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2005

ABSTRACT

Interlibrary Loan entails obtaining copies of library materials not found in the library’s collection on behalf of the library’s patrons (borrowing), as well as providing copies of library materials requested by other libraries (lending). The dynamic nature of today's library environment is well illustrated by the rapid changes occurring in the role of interlibrary loan.

The vision statement of the University of Central Florida Library is: The library performs a central role of adding value to information for the academic community by creatively improving and providing information resources and services. The library strives to create an environment that encourages the pursuit of intellectual endeavors and the creation of new knowledge. In an endeavor to fulfill this vision, the Interlibrary Loan Department at the UCF main library wants to set up a document delivery service within the UCF main campus in order to facilitate research efforts on campus. The document delivery service will include delivery and pickup of library materials for ILL requests by faculty online (via computers).

In this study, we build a Traveling Salesperson model for obtaining a routing sequence for the document delivery service. Next, we analyze this model in order to check the feasibility of the routing sequence in presence of demand (delivery and pickup) by simulating the demand over the route using computer simulation software.

We conclude by validating the model under given conditions and providing route sequence recommendations in the case of extreme demands.

To my belated father, brother and grandparents, my lost ones…

To my mother, my strength…

To my fiancé, my love…

ACKNOWLEDGMENTS

First of all, I would like to thank my advisor Dr. Renee Butler for being a constant support from inception to conclusion of my thesis. If not for her, I wouldn't have even started a thesis. She has been very kind and patient with me, even though I have always been late on my deadlines and troubled her a lot. I appreciate her knowledge, guidance and support and thank her for everything she has done for me.

I would also like to thank Kristine Shrauger, the Head of the ILL Department at UCF library, who has given me access to real time data from the library's database, annual reports and personal knowledge while keeping complete trust in me. I should say she is very knowledgeable in her field and this has helped me build a strong foundation for my study of ILL and DDS. I hope my study is practical enough to provide a real-time document delivery service at UCF main campus.

Next, I would like to thank Dr. Christopher Geiger for agreeing to be on my committee and being an immense help while designing the Arena model for analysis. His 'never say die' attitude and knowledge was successful in building a simulation model with excellent output. I am grateful to him for spending his valuable time on my study.

I would also like to thank Dr. Julia Pet-Armacost, who amazingly found time amongst her busy schedule to lend her valuable suggestions and attend our meetings.

Finally, I would like to thank my mother, who has been a constant motivation and strength throughout my life; and my fiancé who has been with me through thick and thin from the time we have been together. They have been there to feed me, cheer me up, laugh with me, and cry with me, forever. I love you all and I thank God for giving me a wonderful family.

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LIST OF ABBREVIATIONS

UCF	University of Central Florida
ILL	Interlibrary Loan
DDS	Document Delivery Service
TSP	Traveling Salesperson Problem
VRP	Vehicle Routing Problem

CHAPTER ONE: INTRODUCTION

Interlibrary Loan is a very important function of any library as it helps broaden its patrons' pursuit of information by exposing them to a wider range of knowledge by encouraging such an exchange. Fueled by limited buying power, personnel shortages, increased expectations from library patrons, and improved technology, 'access' to library materials has become a major part of library missions. Mary Jackson (1990, 100) summarized the progress of the '80s as: "In the past ten years, interlibrary loan librarians have revolutionized the transmission of ILL requests, witnessed the explosion in the quantity of ILL requests, monitored copyright issues, changed basic library services as the focus has changed from ownership to access, standardized the format and content of the ILL request, and have done all this while handling increased volume of activity in a more timely manner." A current trend is reorganizing the ILL unit of yesterday into the document delivery services of today, with ILL as one function of the new service.

The mission of the University of Central Florida Library is to provide information resources and services to the University community in a manner that supports and enriches the institution's education, research and service missions. The main University Library has a collection of over 1.5 million volumes, including 12,000 current serial subscriptions. In addition to bound volumes, the Library owns approximately 2.8 million microforms and 39,000 media titles. UCF is a partial depository for both United States and Florida government publications. The ILL Department attempts to fill in the gaps in UCF's collection by obtaining books and photocopies of articles needed for educational purposes. The 'Library to Library' service provides transport of books and materials from one UCF affiliated library to another UCF affiliated library. Qualified distance learners taking all UCF web-based courses and living beyond a 30 miles radius outside of any UCF- affiliated institution can receive articles and books via home delivery.

Every library service with a bibliographic database seems to be marketing a document delivery system and the UCF Library is no exception. In this section, we present an overview of the document delivery system that the UCF library wishes to provide its patrons.

Background

Library achievements are qualitative and can be measured only in terms of customer success. They result from a comprehensive process approach to library automation and process improvements. As the importance of Interlibrary Loan and Document Delivery Service continues to grow, more libraries become interested in automating important processes and providing better service to their patrons. The process approach towards improving ILL/DDS can impact many areas of library service, including collection development, reference service, and user training.

The Interlibrary Loan/Document Delivery Services (ILL/DDS) Department at the University of Central Florida (UCF) main campus library in Orlando, Florida processes over 12,000 borrowing (loan) requests serving approximately 30 university departments annually, with the major patrons being faculty, staff and graduate students. Table 1 shows the annual statistics of the ILL/DDS department from July 1994 to July 2004. The 2005 requests represent year-to-date data through April.

Table 1: Yearly Borrowing Requests

Year	Borrowing Requests	% Increase Over Previous Year	% Of Requests from Faculty	Graduate Students
1994	12,585	23%	44%	
1995	15,651	24%	49%	28%
1996	14,054	**-10%**	34%	42%
1997	13,938	**-0.80%**	87%	88%
1998	12,854	**-8%**	35%	42%
1999	16,585	29%	29%	51%
2001	22,709	-	54%	
2002	19,020	**-16%**	57%	
2003	17,312	**-9%**	63%	
2004	12,568	**-27%**	35%	67%

(Source of data: Annual reports, Clio software & ILLiad system from ILL Department)

As shown in Table 1, the number of borrowing requests has shown a steady decline since 2001, with the maximum percentage decline being - 27% in 2004. This decline might be due to other available sources for obtaining literature, for example the internet; and the reluctance of patrons to use the library due to delayed processing of requests and high turnaround times. This evoked a concern for the ILL/DDS Department owing to the importance of this service in the provision of library service.

In addition to this, we have also studied the DDS systems present in other universities including Virginia Tech in Blacksburg, VA and University of Arkansas in Fayetteville, AR in order to gain more knowledge about the implementation and functional aspects of the system. The statistics obtained from these universities were helpful in comparing the state of ILL at UCF. For example, the automation of the ILL system at Virginia Tech in 1999 led to 22,574 borrowing requests in that fiscal year, which was a 52% growth over fiscal 1996. (Kriz, 1999). UCF had only 16,585 borrowing requests in fiscal 1999, which may be due to lack of automation and service efforts. The following figure illustrates the trends in ILL and document delivery at Virginia Tech in the last 15 years.

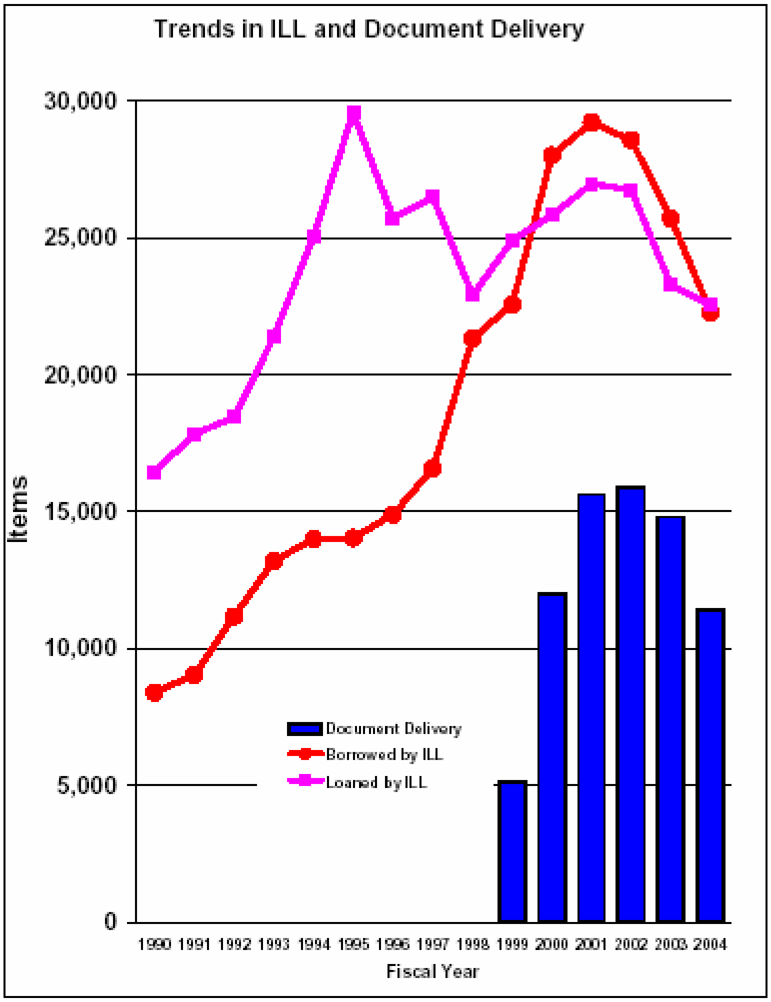

Figure 1: Trends in ILL and Document Delivery at Virginia Tech

Also, the library desires to be more customer service-oriented and wants to market its value through positive feedback from its current patrons, thereby attracting more users (Shrauger, 2004). Finally, in order to fulfill the mission of the University to become one of the top academic research institutions in the nation, it is important that the researchers have easy access to publications- both online and in print.

Hence, in order to fulfill these goals, the ILL/DDS Department upgraded its operations to a web-based system called “ILLiad.” The library hopes that this shift from the Windows-based Clio software will reduce the lead-time and the staff required to process requests and increases the overall efficiency of the Department. In addition to this, the Department wishes to set up a Document Delivery Service in conjunction with the introduction of ILLiad, facilitating research efforts on campus. The document delivery service will include delivery and pickup of loan materials for ILL online requests submitted.

Currently, the ILL/DDS Department provides a document delivery service for electronic media. When a request for electronic media (soft copies of journal articles for example) is filled, ILLiad sends the article to the patron via email. However, these deliveries include only non-returnable loan material. The system does not currently allow for the delivery of returnable loan materials such as books, samples, videos, *etc.*, which need to be physically delivered to the patron and returned to the lending library after usage.

In our study, we develop a Vehicle Routing model with Pickup and Delivery (VRPPD) for the returnable material for the ILL Department. Additionally, we analyze some of the operating conditions, such as stochastic demand, loading and unloading time with respect to the validity of the route.

Problem Statement

In order to model the document delivery system we use a very well known transportation model- the Vehicle Routing Problem (VRP). The objective of a general VRP is to effectively use a given fleet of vehicles to deliver and/or pickup material from a given number of stops, known as nodes (Goetschalckx, 2003). The problem is constrained with respect to some aspects like vehicle capacity, time restrictions (also called time windows), and precedence constraints. The crucial decisions for this problem include determining the number of vehicles required (fleet planning), assigning vehicles to customers (clustering), and determining the sequence of stops or nodes (sequencing) (Goetschalckx, 2003).

Our problem is specific to the UCF main campus in Orlando, where the Library building acts as a single depot and the department buildings, with coordinates (x_i, y_i) and a certain demand D_i, act as delivery and pickup nodes. Vehicle(s) with known capacity will be used for the purpose of delivery and pickup. No time windows are being considered in this study because the document delivery service would function only during normal office hours and the loan material can be delivered to faculty's mailbox if a faculty member is not in their office. The objective of the overall problem is to minimize the total travel distance.

The study will help the library determine the following with respect to the document delivery service upon implementation:

- Daily routing sequence
- Initial investment required
- Operating costs
- Turnaround time of borrowing requests

The main deliverable of the study is a routing sequence for the purpose of document delivery within UCF main Campus in Orlando. A subsequent analysis follows. The route is analyzed with respect to varying demand, where the demand over the route is simulated in order to evaluate the risk of the route becoming infeasible. A likely example of this will occur at the end of the semester when the delivery size will be small and the pickup size will be large. In this case, there is a high chance of exceeding the vehicle capacity if one route is planned. Different combinations of delivery size and pickup size are input into the model and their effect on the routing sequence is monitored. Subsequently, various options for addressing infeasibility in routing sequence under different scenarios are evaluated. The variability in loading and unloading time at each stop is another factor that is analyzed.

Since the problem size, with only 17 nodes, is quite small, it is preferable to solve the problem using exact methods via optimization software rather than lengthy heuristics. Good optimization software produces fast and accurate results for an instance of our size. For this reason, we chose ILOG's OPL Studio version 3.7. OPL Studio includes a variety of optimization tools, like Solver, Scheduler, CPLEX, Hybrid, Concert, DB Link, Views etc. Its modeling language helps develop optimization models quickly and intuitively, avoiding low-level programming tasks (ILOG, Inc., YEAR).

Problem Significance

The benefit of this study is two-fold for the UCF Library and UCF's research needs. The document delivery service designed in this study would have a direct contribution towards the UCF Library by fulfilling its goal of becoming more customer service oriented. It would enable the library to handle increased volume of customer requests and reduce the turnaround time. It would also lead to increased number of users due to improved customer convenience and reduced effort and through positive feedback from its current customers.

The indirect contribution, which is more qualitative than quantitative, is towards UCF's academic research. The document delivery service would help the library to adapt to increased university demand and provide the faculty with fast and easy access to publications- both online and print. The system modeled within this study would provide a unique service which would make UCF one of the first institutions in the state of Florida to implement a document delivery and pickup service.

Additionally, this effort to customize a VRP for the needs of the ILL/DDS system of UCF is an asset to the institution while providing another successful and practical implementation of the well-known theoretical concept of VRP. Using our input analysis, we identify potential growth scenarios with increasing demands. Further, the feasibility analysis of the route using computer simulation accounts for the variability in demand and at the same time provides a route that is capable of handling future growth in demand and daily variations without deviating from the planned route. Incorporating unique features like varying demand and uncertain loading and unloading time to provide a robust route and minimize the effects of infeasibility are a contribution to the research of the VRP.

In Chapter 2, we present the literature review related to our problem. In Chapter 3 we discuss the methodology used for designing the document delivery system. In Chapter 4 we present our findings and analysis. In the last Chapter 5, we state our conclusion, suggest some recommendations and give an insight on future research direction to this study.

CHAPTER TWO: LITERATURE REVIEW

This section contains the relevant literature relating to the document delivery system, including Vehicle Routing and Traveling Salesman Problem.

The Vehicle Routing Problem (VRP) is one of the most widely and effectively used vehicle routing and scheduling problems. While routing refers specifically to the sequence of stops visited by the vehicle(s), scheduling refers to the timing of vehicle loading at the central depot (which may be a distribution center, a plant or a port) and the timing of deliveries at customer nodes (Shapiro, 2001) Some of the applications of vehicle routing include:

- Local delivery of products from distribution center to retail stores
- Local delivery to and installation of propane cylinders at residential customers
- Pickup of liquid nitrogen and oxygen at air products plants by tanker trucks for delivery to industrial customers (Lawler *et al*, 1990)

There are a number of ways in which the vehicle routing problem has been defined by different authors. According to Min (1991), VRP involves minimizing the total distribution cost or travel distance for a fleet of capacitated vehicles given a set of known customer locations. According to Goetschalckx (1989), the VRP develops a set of routes such that all delivery points are serviced, the demands of all points assigned to each route do not violate the vehicle capacity, and the total distance traveled by all vehicles is minimized.

Classification of Vehicle Routing Problem

According to 'Logistics Systems Design' (Goetschalckx, 2003) vehicle routing problems are classified according to two criteria:

1. Number of vehicles:

The problem can be classified as S*ingle* or M*ultiple* VRP depending on the number of vehicles used or required. If only a single vehicle is used, there is no assignment decision of which task to be executed by which vehicle, which makes the problem easier to solve.

2. Consideration of vehicle status before and after execution of transportation service:

If the prior and posterior status of the vehicle(s) is not considered, the transportation tasks can be thought of as if performed by different and independent vehicles. This class is called *Origin-Destination routing.* If the prior and posterior status of the vehicle(s) is considered, the transportation tasks can be thought of as jointly served, i.e, when service of one request changes the status of the vehicle so that it impacts the service of other transportation requests. This class is called *Vehicle Roundtrip routing*. The first class considers the transportation tasks more from a shipper point of view since it does not consider vehicle status after transportation request has been completed whereas the second class considers the transportation tasks more from a carrier point of view since it has to consider vehicle status.

The following table illustrates this classification, along with acronyms used for each problem:

Table 2: Classification of Transportation Models

	Number of Vehicles	
Vehicle Status	Single	Multiple
Request-Destination	Single vehicle Origin-Destination (SPP)	Multiple vehicle Origin-Destination (NF) Only
Prior & post	Single Vehicle Roundtrip (TSP)	Multiple Vehicle Roundtrip (VRP)

(‘Logistics Systems Design’ by Marc Goetschalckx, 2003)

Single vehicle Origin-Destination Routing:

Single vehicle Origin-Destination Routing, also called Shortest Path Problem (SPP), is the route of a single vehicle from an origin to a destination. A common application is the driving directions between any two addresses in continental USA from different websites like Mapquest.com. An additional example is replacing a particular machine by a newer model. In this case, each machine replacement decision can be represented as an arc from the starting period to the end period of the use of that machine. The least cost equipment replacement schedule can then be found as the shortest path from the start to the end of the planning horizon. The SPP is commonly solved with Dijkstra's Algorithm.

Multiple vehicle Origin-Destination Routing:

Multiple vehicle Origin-Destination Routing represents a network flow problem consisting of nodes (sources or supply nodes and sinks or demand nodes) and arcs (directed, capacitated, costs) and is frequently applied in production-distribution planning and operator scheduling. Some network variations include Transportation, Transshipment, Min cut-max flow network, and Min cost network. These problems are commonly solved as linear programs. Figure 2 represents a generic network flow problem.

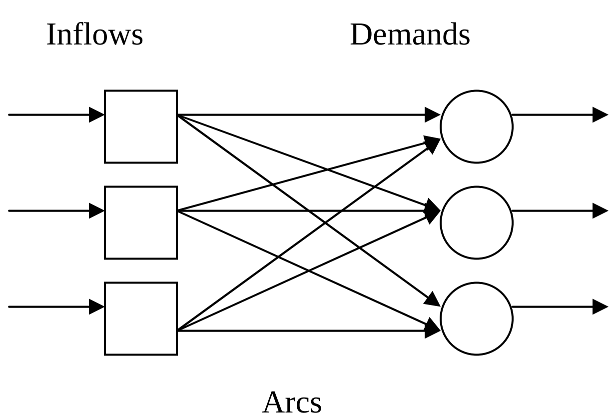

Figure 2: Multiple Vehicle Origin-Destination Network Illustration

Single vehicle Roundtrip Routing:

Single vehicle Roundtrip Routing, also called the Traveling Salesman Problem, is typically used for applications such as school bus trips for picking up and dropping off students and daily deliveries of mail/packages via FedEx, UPS or USPS. Many heuristic techniques and other specialized branch and bound algorithms are used for solving single vehicle roundtrip routing problems. Figure 3 below demonstrates a Single vehicle Roundtrip Routing or tour.

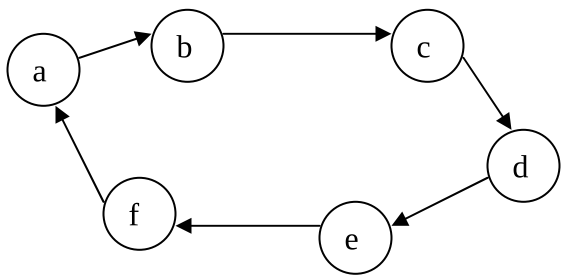

Figure 3: Traveling Salesman Problem Illustration

Multiple Vehicle Roundtrip Routing:

Multiple vehicle Roundtrip Routing is an extension of the general VRP that effectively utilizes a given fleet of vehicles to visit a given a number of stops, known as nodes, for delivery and/or pickup. The problem is constrained with respect to some aspects like vehicle capacity, time windows, precedence constraints etc. Crucial decisions include determining the number of vehicles required (fleet planning), which vehicle should serve which customers (clustering) and determining the sequence of stops or nodes (sequencing). The VRP has several variations including Linehaul-Backhaul, Vehicle Routing with Time Windows, Vehicle Routing and

Scheduling, Mixed Pickup and Delivery, and Simultaneous Pickup and Delivery. Below we discuss a few of these variations in more detail.

VRP with Backhauls (VRPB)

Also called the Linehaul-Backhaul problem, the VRP with Backhauls (VRPB) is a delivery and pickup problem where all deliveries must be made before pickups on each route. Linehaul (delivery) points are sites which receive goods from the central depot or distribution center (DC) and backhaul (pickup) points are sites which send goods back to the DC. According to Goetschalckx and Jacobs-Blecha (1989), the standard VRP is a special case of the linehaul-backhaul problem with the number of backhaul points equal to one. They state that the importance of this kind of problem lies in the effort to reduce distribution costs by taking advantage of the unused capacity of an empty vehicle traveling back to the DC. The authors discuss some of the exact procedure and heuristic procedure approaches which are used for solving VRP. Exact procedures include branch and bound, dynamic programming, and cutting plane algorithms. A few heuristic procedures include cluster-first-route-second, route-first-cluster-second, savings-and insertion algorithms, as well as improvement and exchange algorithms.

Goetschalckx and Jacobs-Blecha (1989) use a two phase solution method to solve this problem. The initial solution to the problem is found using Spacefilling curve heuristics (SFC) like Greedy algorithms and K- Median algorithms. Subsequently, the initial solution is optimized by performing computational analysis for comparison of greedy vs. K-median algorithms in order to find the better of the two methods to solve VRPB. A critical property of spacefilling curves is their tendency to preserve "nearness" among points due to visiting all points in one region before going on to a different region.

VRPB has caught a lot of attention both in the past and at present. A large amount of literature on VRP relates to VRPB. For example, Deif and Bodin (1984) present an extension to savings method for linehaul-backhaul. Toth and Vigo (1996) solve a similar problem by first clustering separately, then matching the clusters and solving TSPs, followed by suggesting improvement procedures. Osman and Wassan (2002) propose an initial solution based on saving-insertion or saving-assignment, plus reactive tabu search.

VRP with Time Windows

According to Min (1991), with the development of just-in-time (JIT) philosophy and increased importance of customer service, the temporal aspects of VRP cannot be disregarded. Classical VRP gives the most cost-effective sequence of delivery routes from the DC to customers. However, in many practical situations, instances arise where the optimal cost-effective routing sequence does not necessarily guarantee timely delivery service. Additionally, it is often required in distribution problems that customers be served within certain specific time windows. Hence, it is important to consider multiple objectives of travel cost as well as travel time. The author states that time windows can be specified in two ways:

1. "Hard" or tight time windows are imposed in such a way that both the lower and upper bound restrictions must not be violated under any circumstances. They arise in instances like designing schedules for school buses, postal carriers, and bank couriers.
2. "Soft" or loose time windows act as goals rather than restrictions and are imposed in such a way that the lower and upper bound restrictions need to be satisfied, but can be violated

with a penalty or traded-off with cost for the benefit of timely service. Examples of soft time windows include the dial-a-ride problem, routing of urban buses or street cars, and library material distribution.

In Min (1991), the author develops a model for multi-objective VRP with soft time windows and applies it to the case of a public library distribution system in the Columbus, Ohio metropolitan area. He uses mixed-integer goal programming for modeling purposes. The model is simple and flexible and can be viewed as an extension of an assignment-based integer linear program. Moreover, it does not require any sub-tour elimination constraints. A sensitivity analysis of goal weights demonstrates the flexibility of the model to tighten the time windows. This is a unique effort as in existing VRP studies have been confined to hard time windows and have ignored the multi-objective nature of the problem.

VRP with Simultaneous Pickup and Delivery (VRPPD)

Min (1989), Halse (1992) and Gendreau *et al.* (1999) are contributors to the research on this variation of the vehicle routing problem. The article by Min (1989) was the first paper to address simultaneous pickup and delivery with vehicle routing. As the name suggests, simultaneous pickup and delivery the vehicle is required to simultaneously drop off and pickup goods at the same stop. He justifies the need for simultaneous delivery and pickup in real-world situations like airlines, school buses, grocery-product distributors and library material distribution systems. He presents a model and solution procedure for a multi-vehicle routing problem with simultaneous delivery and pickup (M-VRPPD) for the public library distribution system in Franklin County, Ohio.

In the paper, Min (1989) uses a stepwise approach that first uses a clustering heuristic to group customer nodes according to their geographical proximity in such a way that the total delivery/pickup size of customers within the cluster does not exceed vehicle capacity. Then he assigns drivers to the two clusters formed in the previous step. The first step is forming a routing sequence using the single traveling salesman problem (TSP) with mixed load constraints. Mixed load constraints are an important and unique aspect of this model. They ascertain that the cumulative load at each node do not exceed the vehicle capacity. As TSP is in a class of NP-hard problems, it is difficult to solve the above formulation as an integer program effectively using the branch and bound technique. Hence, the author uses a solution scheme where he first solves the single TSP without the mixed load constraints. From the solution obtained, he sets zeros and ones for the decision variable and confirms the feasibility by satisfying the mixed load constraints. If the mixed load constraints are not satisfied, the routing is revamped by adding a larger number to the arc starting from any node ending at a node where cumulative loads exceed the vehicle capacity, thus preventing infeasible delivery/pickup sequence. The study proves to be a success in that its results indicate substantial time and distance savings. A similar approach is used in our project.

Summary

As can be observed from the afore mentioned articles, VRP has been a subject of intensive research and possesses a vast pool of literature. These articles reflect a variety of methods and techniques that are utilized for solving different types of VRPs, varying from standard branch and bound algorithms to heuristic procedures. This gives a good base for selecting the most suitable method for solving a particular problem.

Our problem of designing a document delivery system for the UCF library is similar to Min's (1989) multi-vehicle vehicle routing problem with simultaneous pickup and delivery problem with the case study of the public library distribution system in Franklin County, Ohio. The kind of model developed is fairly straightforward and practical for applying in real-world cases and would be able to satisfy the requirements of our system. Hence, our basic solution approach is similar to his, where we identify an optimal route by an integer programming model and subsequently verify through simulation that the maximum capacity of the vehicle is not exceeded. We ignore time windows for our problem, as the deliveries will be made to faculty mailboxes if they cannot be made to the faculty offices directly.

The next chapter discusses the methodology we used in order to tackle the problem and fulfill our goal of designing a document delivery system using Vehicle Routing.

CHAPTER THREE: METHODOLOGY

The objective of this research is to build a vehicle routing model for the purpose of document delivery of interlibrary loan material within the UCF main campus. This chapter explains the methodology used to build this model. Specifically, in this chapter we will:

1. define our problem statement
2. present an overview of the ILL system
3. describe input data needed and collection procedure
4. model the TSP problem
5. analyze the results and check the validity of routing sequence

Problem Statement

In the context of this thesis, we develop a routing sequence for the purpose of document delivery of ILL materials within the UCF main campus at Orlando. The library building acts as a single depot where material originates. The department buildings act as delivery and pickup nodes and have coordinates (x, y), delivery size (D), and pickup size (P). We assume the vehicles are electric carts with a capacity of 500 pounds. No time windows are considered at this point in time. The objective is to minimize the total travel distance to meet the delivery and pickup requests.

In addition to obtaining a routing sequence, we will investigate several what-if scenarios to test the robustness of the route. We are interested in two main robustness criteria: exceeding the vehicle capacity and exceeding the maximum time to complete the entire route.   For testing the vehicle capacity, we vary the delivery and pickup size. To test the route completion time, we vary the loading and unloading time at each stop.

The following assumptions are made while designing the route:

- Delivery and pickup occurs simultaneously in the route.
- All of the delivery material to be delivered on a particular day arrives at the same time on that day.
- Delivery amounts at each node are constant and known whereas pickup amounts vary according to the selected probability distribution. In other words, we assume away stochastic demands.
- Pickups are made at every stop daily irrespective of the number of pickups. Each department is assumed to have a drop box for returning the ILL loan material.
- Delivery material is pre-sorted according to the department or building before the routing starts to save up on delivery time.

Overview of ILL

Interlibrary Loan is a service provided to current faculty, students, and staff, and others affiliated with the University to access materials not owned by the library. Interlibrary Loan services support the research, study, and teaching needs of the university community.

Figure 4 gives an overview of the processes of the ILL system. The patron identifies a book or item from the library catalog or database and checks to see if it is in the libraries collection. If the library owns the book/loan material, it is checked out to the patron. If the library does not own the book/loan material and the patron wishes to obtain it, he submits a loan request to the library wherein the library would "borrow" his loan request from other "lending" libraries within the United States. The library submits a loan request to the Online Computer Library Center, Inc. (OCLC), which returns a list of potential lending libraries. A request is then sent to a lending library chosen based on their geographic proximity, turnaround time, and other factors. When the borrowing library receives the material, the patron is notified and the book/loan material is checked out to the patron. On or before the due date, the book/loan material returned to the library, and is sent back to the lending library. The request is then complete.

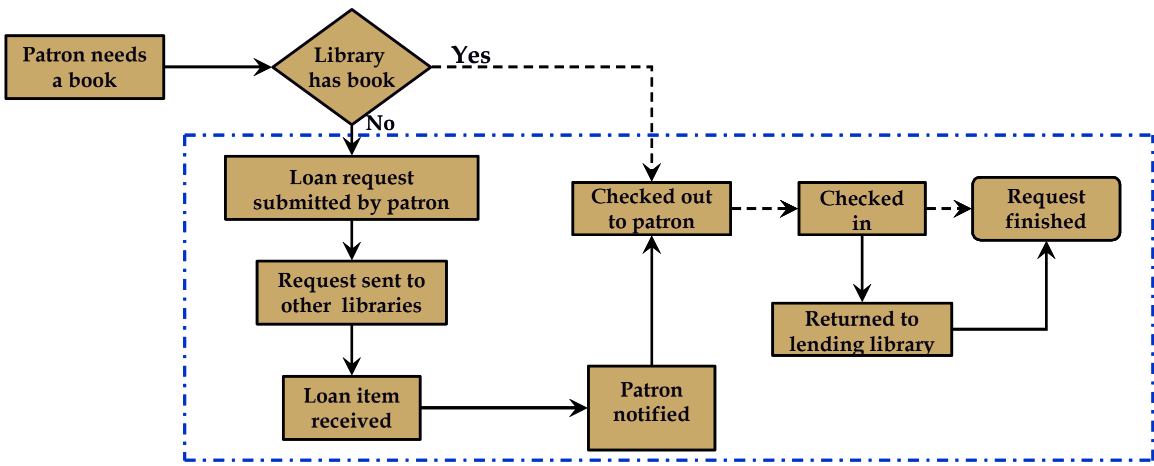

Figure 4: ILL Process Overview

Data Collection

This research project is based on a real world application and as such requires real data, which implies that we need to use current data as is available to make decision for the immediate future. Fortunately, the Head of ILL/DDS Department was able to provide much of the pertinent data from the department's database and personal knowledge. In addition to the basic borrowing and lending workflow that we discussed above, the ILL Department provided the ILL statistics on requests by department since 2001 for past years using past annual reports. This data is summarized in Table 1 earlier.

The borrowing requests of faculty can be further broken down into sub-categories. The reporting categories or departments of the ILL system do not exactly coincide with academic departments of the University; however, this is the best breakdown available of the historical data. We summarize the number of borrowing requests by faculty in these categories in Table 3 below.

Table 3: ILL Borrowing Requests of Faculty by Department

Dept/Year	**2001**	**2002**	**2003**	**2004**
Psychology	2185	2238	2111	2146
Nursing	994	771	627	847
Education	1693	1531	1443	1564
English	807	761	521	743
History	640	682	531	825
Industrial engg	298	-	-	-
Mechanical & Aerospace engg	415	-	-	-
Electrical engg	237	-	-	-
Civil & environmental engg	171	-	-	-
Social Work	230	-	119	-
Public admn	305	317	238	199
Foreign language	1142	932	880	1017
Biological sciences	726	497	517	712
Communicative Disorders	291	253	246	248
Mathematical Science	245	228	176	239
Criminal justice	186	138	170	-
Political science	271	206	213	197
Chemistry	482	284	-	263
Molecular & Microbiology	187	270	310	570
Engineering	1110	1908	1833	1817
Sociology	393	487	331	504
Communication	304	-	121	169
Business Administration	246	245	154	140
Library	239	183	272	466
Creol	234	282	267	235
Health Science	207	180	110	223

Next, we need to determine the travel distances between nodes. We use an AutoCAD map of UCF to identify the academic buildings that act as delivery and pickup nodes. Each building may house one or more departments. The coordinates are the approximate center of the building. The details of building number, department housed in the building, and the (x_i, y_i) coordinates of the building are shown in Table 4 below.

Table 4: Building Coordinates

Node	Bldg no.	Department	X coordinate	Y coordinate
1	2	Library	190296.6	19280.1
2	21	Biological Science	190264.2	19279.2
3	20	Business Administration 2	190344.3	19278.2
4	94	Business Administration	190345.9	19292.8
5	45	Engineering 1& 2	190335.5	19302.9
6	91	Health & Public Affairs 1	190348.6	19326.4
7	80	Health & Public Affairs 2	190349.4	19339.4
8	90	College of Arts & Science	190357.1	19343.2
9	87	Colbourn Hall	190277.1	19370.4
10	18	Howard Phillips Hall	190274.3	19298.9
11	14	Brunett Honors College	190278.4	19280.6
12	95	Communications Building	190287.4	19322.4
13	75	Computer Science Building	190276.8	19370.1
14	54	CREOL	190319.9	19299.9
15	53	Chemistry	190373.4	19306.0
16	5	Math & Physics	190331.2	19277.4
17	12	Education	190316.8	19270.9

The following Figure 5 illustrates the actual locations of the buildings under consideration as nodes, as well as the library, *i.e.*, the depot. The numbers indicated in the figure are the actual building numbers.

Figure 5: Location of delivery and pickup nodes on UCF main campus map

After obtaining the *(x_i, y_i)* for each building, the inter-nodal travel distances are calculated as Euclidean distances using the following formula:

$$\text{Distance between node } i \text{ and node } j = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \qquad (1)$$

Due to the relatively small size and circular shape of UCF main campus, and the number of transportation routes, Euclidean distances give a reasonably good estimate of inter-nodal distances, which are shown in the matrix in Table 5. Also, the many walkways on campus allow for approximate straight line travel between buildings. A large value, 10000 mm, is input on the diagonal in order to construct valid routes. It will prevent routes going out and coming into the same node.

Table 5: Inter-nodal Distance Matrix

Bldg no.	**2**	**21**	**20**	**94**	**45**	**91**	**80**	**90**	**87**	**18**	**14**	**95**	**75**	**54**	**53**	**5**	**12**
2	10000	32.41	47.78	50.91	45.12	69.61	79.38	87.39	92.39	29.17	18.20	43.25	92.11	30.56	81.05	34.72	22.22
21	32.41	10000	80.15	82.83	75.18	96.69	104.31	112.79	92.12	22.19	14.27	49.00	91.73	59.42	112.44	67.04	53.27
20	47.78	80.15	10000	14.64	26.18	48.35	61.37	66.21	114.12	73.02	65.97	72.05	114.01	32.65	40.20	13.16	28.49
94	50.91	82.83	14.64	10000	14.46	33.71	46.73	51.63	103.75	71.85	68.59	65.56	103.68	26.95	30.50	21.29	36.42
45	45.12	75.18	26.18	14.46	10000	26.88	39.04	45.70	89.33	61.36	61.35	51.95	89.26	15.93	37.98	25.87	37.09
91	69.61	96.69	48.35	33.71	26.88	10000	13.02	18.83	83.99	79.18	83.82	61.33	84.05	39.06	32.11	52.00	63.96
80	79.38	104.31	61.37	46.73	39.04	13.02	10000	8.57	78.69	85.27	92.19	64.29	78.82	49.30	41.13	64.62	75.86
90	87.39	112.79	66.21	51.63	45.70	18.83	8.57	10000	84.50	93.84	100.55	72.72	84.66	57.08	40.63	70.72	82.77
87	92.39	92.12	114.12	103.75	89.33	83.99	78.69	84.50	10000	71.52	89.86	49.14	0.45	82.52	115.89	107.64	107.18
18	29.17	22.19	73.02	71.85	61.36	79.18	85.27	93.84	71.52	10000	18.83	26.83	71.16	45.59	99.33	60.84	50.92
14	18.20	14.27	65.97	68.59	61.35	83.82	92.19	100.55	89.86	18.83	10000	42.76	89.51	45.77	98.34	52.90	39.61
95	43.25	49.00	72.05	65.56	51.95	61.33	64.29	72.72	49.14	26.83	42.76	10000	48.86	39.53	87.55	62.80	59.30
75	92.11	91.73	114.01	103.68	89.26	84.05	78.82	84.66	0.45	71.16	89.51	48.86	10000	82.38	115.93	107.48	106.96
54	30.56	59.42	32.65	26.95	15.93	39.06	49.30	57.08	82.52	45.59	45.77	39.53	82.38	10000	53.85	25.18	29.17
53	81.05	112.44	40.20	30.50	37.98	32.11	41.13	40.63	115.89	99.33	98.34	87.55	115.93	53.85	10000	50.98	66.60
5	34.72	67.04	13.16	21.29	25.87	52.00	64.62	70.72	107.64	60.84	52.90	62.80	107.48	25.18	50.98	10000	15.80
12	22.22	53.27	28.49	36.42	37.09	63.96	75.86	82.77	107.18	50.92	39.61	59.30	106.96	29.17	66.60	15.80	10000

All distances are in millimeters
Scale of map: 1 mm= 0.0039 mile

In order to stay within the vehicle capacity on a route, it is necessary to obtain the delivery and pickup size at each node. From the data presented in Table 3, we calculate the average annual demand (number of books) over four years, from 2001 to 2004. Demand data from the year 2005 is not included because it is only a partial year of data. The average daily demand is calculated by dividing the average annual demand by number of working days in a year (261 days, excluding holidays). The average daily demand by department is shown in Table 6.

Table 6: Delivery size (number of returnables)

Department	Average Annual Demand 2001-2004	Average Daily Demand 2001-2004
Psychology	2170	8
Engineering	1667	6
Education	1557.75	6
Foreign languages	992.75	4
Nursing	809.75	3
History	669.5	3
Engineering	708	3
Biological Sciences	613	2
Molecular Bio. & Microbiology	334.25	1
Sociology	428.75	2
Library	290	1
Music	181.5	1
Anthropology	217.75	1
Chemistry	330.25	1
Communicative disorders	259.5	1
Mathematics	222	1
Creol	254.5	1
Liberal Studies	168.25	1
Health Sciences	174	1
Public Administration	264.75	1
Political science	221.75	1
Communications	188.75	1
Physics	76	0
Computer science	159.25	1
Business Administration	196.25	1

However, due to the weight capacity restrictions of the vehicle(s) carrying delivery material from the library, the weight of the delivery size is more important than the number. We assume the average weight of a returnable to be four pounds and calculate the daily demand in terms of pounds. According to personal communication with K. Shrauger, the average weight of the returnable with packaging is 3 to 4 lbs. We assume the more conservative estimate of 4 lbs. Table 7 shows the delivery size in terms of weight for each building under consideration as a delivery and pickup node. It is to be noted that one building may house more than one department; hence the number of buildings in Table 7 are fewer than the departments in Table 6. Appendix B shows detailed calculations of delivery size in pounds.

Table 7: Delivery size (in pounds)

Building No.	**Department**	**Delivery size (pounds)**
21	Education	28
20	Biological Science	8
94	Business Administration 2	4
45	Business Administration	4
91	Engineering 1& 2	28
80	Health & Public Affairs 1	20
90	Health & Public Affairs 2	12
87	College of Arts & Science	4
18	Colbourn Hall	48
14	Howard Phillips Hall	44
95	Brunett Honors College	4
75	Communications Building	4
54	Computer Science Building	4
53	CREOL	4
5	Chemistry	4
12	Math & Physics	4

Finally, the delivery vehicle(s) to be used must be determined. After evaluating various options like customized golf cars and Gem electric cars, we conclude that a customized golf car with an aluminum box at the rear, a payload capacity of 500 pounds, and a cost of approximately $3,600 is selected. Due to the relatively small size of UCF main campus and due to the fact that the total delivery amount is 224 lbs or half the payload amount, initially one vehicle is considered. The decision on the type of vehicle depends upon the delivery size requirements and budget constraints.

Modeling

Our modeling procedure is based on the solution procedure of Min (1989) for designing a similar document delivery system for Franklin County, Ohio. The author first uses a simple TSP to obtain an initial routing sequence for all nodes within the UCF main campus using sub-tour elimination constraints. A subsequent analysis follows, which validates the route by ensuring that cumulative loads at each node do not exceed the vehicle's capacity. However, there exist a few differences in our modeling approach. Due to the small size of the UCF main campus and restrictions on transportation methods, we use one small electric golf car instead of two large trucks (as in Min's model), which can travel within the campus on walkways (instead of roads as in Min's model).

Initially, we solve a simple Traveling Salesperson Problem (TSP) using an exact optimization algorithm with an integer program in order to obtain a routing sequence. This method often creates several smaller loops, called sub-tours, instead of one big loop. Additional constraints are added to eliminate the sub-tours and get a valid routing. However, this routing generated by a TSP algorithm may not be feasible because it may not satisfy the vehicle capacity at all stops. Subsequently, the next step is to assure that cumulative load at each node does not exceed the vehicle capacity limit. This is done using a separate analysis presented in the next sub-section. Below, we discuss the mathematical formulation in more detail.

Mathematical Formulation

A routing sequence is generated for the TSP. The problem is described as follows: Given a collection of cities and the cost of travel between each pair of them, the traveling salesperson problem, or TSP for short, is to find the cheapest way of visiting all of the cities and returning to the starting point. In the general version, the travel costs are symmetric in the sense that traveling from city X to city Y costs just as much as traveling from Y to X. The simplicity of the statement of the problem is deceptive. The TSP is one of the most intensely studied problems in computational mathematics and yet no effective solution method is known for the general case. Although the complexity of the TSP is still unknown, for over 50 years its study has led the way to improved solution methods in many areas of mathematical optimization. The resolution of the TSP would settle the P versus NP problem (The Logistics Institute, Georgia Institute of Technology, 2005).

In our model, the library acts as the central depot and the department buildings act as delivery and pickup nodes. We use one vehicle with a capacity of 500 pounds for the purpose of delivery and pickup.

First we define the variables and parameters.

- *Variables*

  $x_{ij} \in \{0, 1\}$ is 1 if the vehicle takes arc *(i, j)* and 0 otherwise

- *Parameters*

  d_{ij} = Euclidean or straight-line distance between node *i* and node *j*

  N = total number of nodes

The objective of the overall problem is to minimize the total distance traversed by the vehicle. The mathematical formulation of the objective is as follows:

$$\text{Min} \sum_{i=1}^{N} \sum_{j=1}^{N} d_{ij} \times x_{ij} \tag{2}$$

The constraints consist of logical expressions to build a valid route, that is the vehicle starts at the central depot, visits each node exactly one time, and then returns to the depot. Below we define and explain each of the constraints.

1. The vehicle should leave each node, including the depot, *i.e.,* the library. The mathematical formulation of this constraint is as follows:

$$\sum_{i=1}^{N} x_{ij} = 1 \qquad \forall j \tag{3}$$

2. The vehicle should enter each node only once. The mathematical formulation of this constraint is as follows:

$$\sum_{j=1}^{N} x_{ij} = 1 \qquad \forall i \tag{4}$$

3. Lastly, we need to eliminate sub-tours. The vehicle should make only one complete tour of all of the nodes. The above constraints alone can create sub-tours or smaller loops that visit a subset of the nodes. A TSP model often results in a set of sub-tours *S* among *N* nodes, because of lesser inter-nodal distances between adjacent nodes. The mathematical formulation of the sub-tour elimination constraint is as follows:

$$\sum_{i \in S} \sum_{j \in S} x_{ij} \leq |S| - 1 \qquad \forall S \subset N \tag{5}$$

Computer Model

After building the mathematical model, the next step is solving the model using appropriate methods. As discussed earlier, there are many methods which can be used in order to solve a TSP, for example, branch and bound algorithms, heuristic procedures, integer programming, multi-objective goal programming, etc.

Since our problem is relatively small containing only 17 nodes, it is preferable to solve the problem using exact methods via optimization software rather than to invest in the development of heuristics. Good optimization software produces fast and accurate results for an instance of our size. From among the available software packages, we choose ILOG's OPL Studio version 3.7 (ILOG, Inc., 2005). It is one of the market's most comprehensive modeling systems. Its Optimization Programming Language (OPL) helps develop optimization models quickly and intuitively, avoiding low-level programming tasks like memory management. Hence, the time necessary to deliver high-performance optimization applications is considerably reduced. Additionally, the descriptive OPL syntax produces substantially simpler code than traditional programming languages and the graphical user interface helps structure problems and select solution strategies.

The OPL Studio code consists of a project file that includes a model file and a data file. As the names suggest, the model file contains the actual code for the formulation while the data file contains the data to be used with it. The sub-tour elimination constraints are added to the formulation when sub-tours are formed within the route. These sub-tour elimination constraints were added iteratively until a single valid tour was obtained. The results of the OPL Studio model are discussed in the next chapter and the codes for both these files are given in the Appendix.

Analysis

After solving the TSP model and obtaining a single route, our major concern is checking the feasibility of the delivery/pickup sequence in order to ensure that the cumulative loads at each node does not exceed the vehicle's capacity limit. In order to perform this analysis, we use Arena® Version 8.01, one of the most popular types of simulation software. Arena combines the ease of use found in high-level simulators with the flexibility of simulation languages and even all the way down to general-purpose procedural languages like Microsoft® Visual Basic ® programming system or C. It provides alternative and interchangeable *templates* of graphical simulation modeling and analysis *modules* that can be combined to build a fairly wide variety of simulation models. Modules from different *panels* can be used together in the same model.

Firstly, a base model with the route obtained from the previous sub-section and original values and attributes is created. Next, an analysis is done by changing few values, such as delivery and pickup amounts and delivery and pickup times in the base model.

Below we discuss the parts or modules of our Arena simulation model.

- *Create:* This module creates a single vehicle for the purpose of routing.
- *Write:* Writes the headings to the output file with the given overriding file format.

- *Assign:* Assigns the maximum capacity of the vehicle, current capacity of the vehicle after loading the delivery material from the library at the beginning of the routing, and initializes the stop number.
- *Assign:* Obtains the travel time to the current delivery and pickup location. These times are calculated using the average speed of golf cars within the campus, which varies from 12 mph (lower bound) to 20 mph (upper bound). The travel time from one stop to another is assumed to be a Triangular distribution with a mode of 4 minutes or 6 minutes depending upon the pedestrian traffic in the area. The lower bound is 3 minutes or 5 minutes and the upper bound is 6 or 7.5 minutes respectively. For example, in the southern part of the UCF main campus, around the library and the Millican Hall, there is usually high pedestrian traffic, which will require lowering vehicle speeds. Hence, for stops lying in this region the distribution for travel time will be TRIA (5, 6, 7.5). For those stops in the northern (less congested) region, the vehicle speed will be TRIA (3, 4, 6). *Process:* This module takes into account the travel time to the current delivery pickup location using the given expression for travel time.
- *Read:* Reads the delivery amounts for each stop from a text file.
- *Assign:* It generates arrival time, pickup amount and vehicle current used capacity. The pickup size is an exponential distribution with a mean of 20 lbs at every stop, or EXPO (20). This distribution is chosen due to the random nature of the pickup size.
- *Process:* Performs delivery and pickup using the given expression for delivery and pickup time. This module takes into account the loading and unloading time required

at each stop. The following table shows the steps and respective formulae used to calculate the delivery and pickup / load and unload time:

Table 8: Calculating loading and unloading time

Process	**Time taken (in minutes)**
Parking the car	0.25
Unloading the delivery material and loading it onto a hand truck or trolley	0.1*Delivery size in lbs / 4lbs
Traveling to the faculty offices	1 per department +1 per floor
Delivering the loan material	1 *Delivery size in lbs / 4 lb
Loading the pickup material on the hand truck	0.1*Pickup size in lbs * Dept / 4 lbs
Returning to the truck	0.5 per floor
Unlocking the car and loading the pickup material back on the car	0.25 + 0.1*Pickup size in lbs

For simplicity, we assume the number of floors in all buildings to be 3, the final formula for delivery and pickup / load and unload time inputted into the Arena model is as follows:

$$5 + 0.275 * \text{Delivery size in lbs} + 0.025 * \text{Pickup size in lbs} (1+ \text{Dept}) + 1* \text{Dept} \qquad (6)$$

This formula indicates that the load unload time depends only on the delivery and pickup amounts and number of departments housed in the building.

- *Assign:* Records the departure time of the vehicle from current delivery pickup location.
- *Decide:* Decides whether the vehicle is currently over `its capacity after performing the delivery and pickup at each stop.
- *Assign:* Assigns identification for over capacity at that particular stop if the decision before is true. For instance, if the vehicle is over its capacity, the module indicates ‘1’, otherwise it indicates ‘0’.
- *Write:* Writes the delivery pickup output at current location to the output file.

- *Decide:* Decides whether all 16 stops have been traversed or not. If true, the vehicle travels to the library, otherwise it goes back to the assign module for obtaining the travel times of the next delivery pickup location.
- *Assign:* Generates the travel time back to the library by using the given expression for travel time.
- *Assign:* Records the return time of the vehicle to the library.
- *Process:* This module takes into account the travel time to the library using the given expression for travel time.
- *Write:* Writes the delivery pickup outputs of the final location in the given overriding file format.
- *Dispose:* Indicates that the vehicle is back at the library.

Figure 6 shows a flowchart of the complete process used for analysis using simulation.

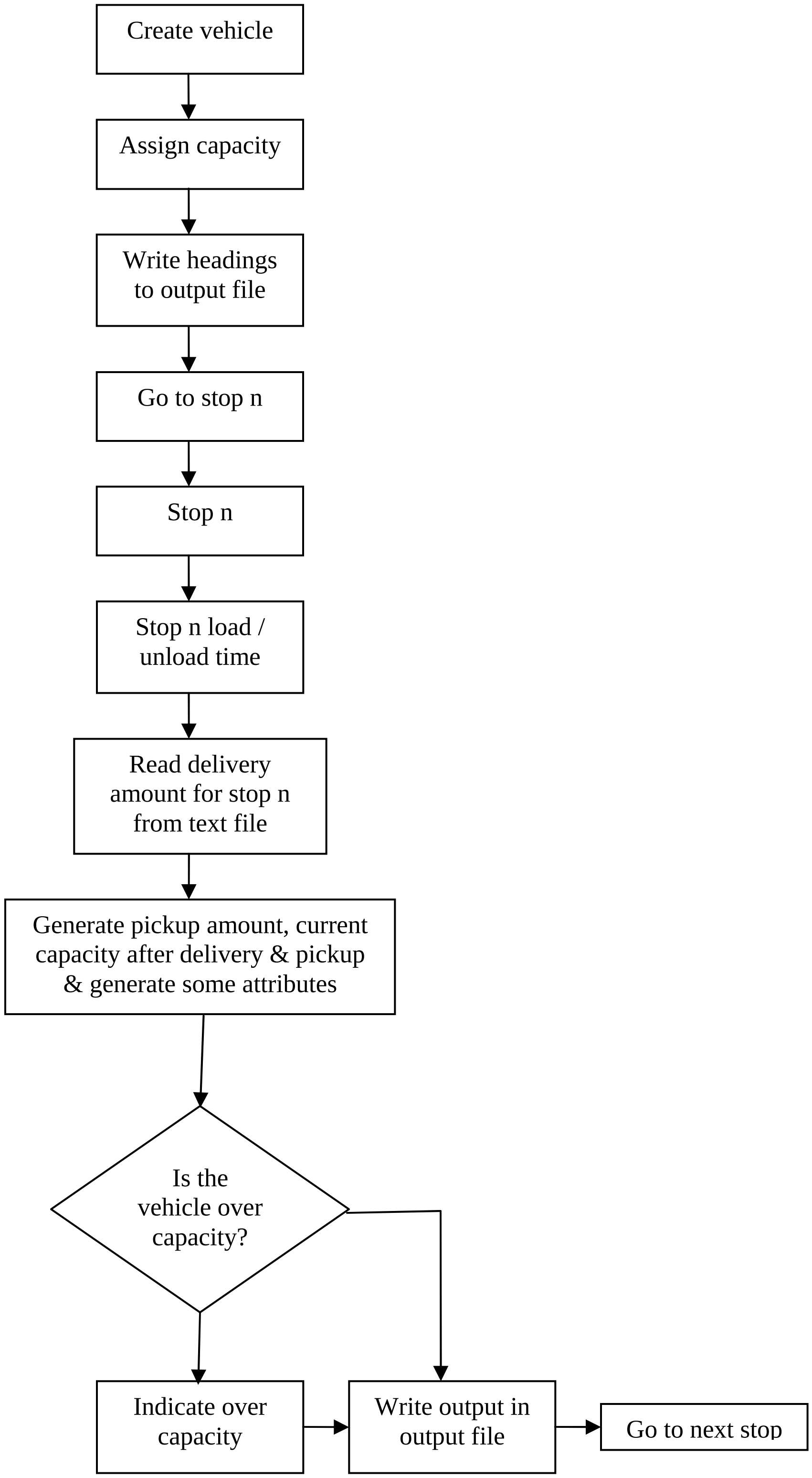

Figure 6: Flowchart of Analysis model

Figure 7 illustrates a part of the screenshot of our Arena model, which looks similar to the flowchart shown in Figure 6. The base time units for the model are minutes. The model is run for 15 replications (single complete routing tour) with no warm up period, infinite replication length and no terminating condition.

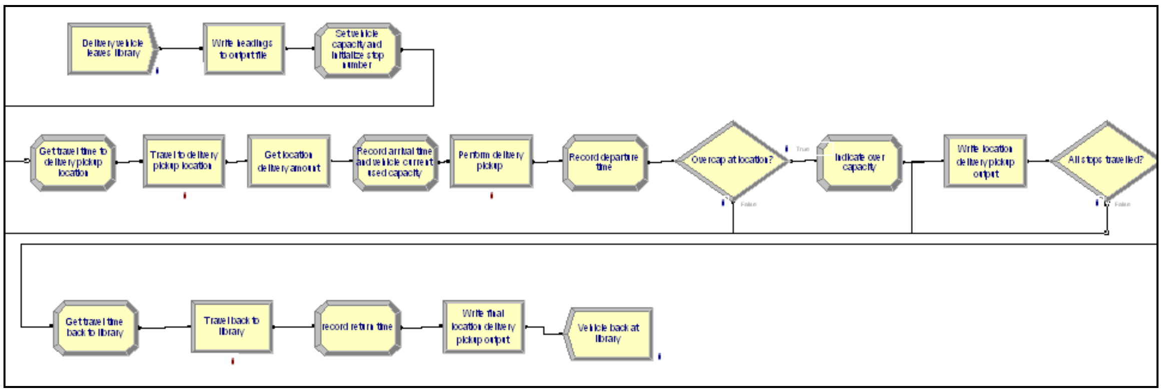

Figure 7: Arena Model Screenshot

In order to decide the number of replications to be run, we perform a simple analysis to find the precision with which the total travel times are reflected in the output file. We calculate the half-width of the results of total travel times. Table 9 shows these calculations:

Table 9: Half-width calculations for 15 and 30 replication runs

Statistics	**Value for 15 replications**	**Value for 30 replications**
Count	15	30
Sum	4306.810	9638.370
Average	287.121	321.279
Standard Deviation	8.64	8.94
Confidence Level	95%	95%
$t_{n-1,1-\alpha/2}$	2.045	2.045
Half-Width	3.224	3.337
CI Lower Limit	283.896	317.942
CI Upper Limit	290.345	324.616
Half Width as % of Average	1.12%	1.04%

The table above indicates the precision level for 15 and 30 replications. It is observed that for 15 replications, the half-width if 1.12% of the average whereas for 30 replications it is 1.04% of the average, which is not significantly different. Hence, we run 15 replications in order to save computational time.

The analysis model will check the feasibility of our routing sequence using the following main parameters:

- Pickup size: We perform several iterations by changing the pickup size in the assign module to EXPO (28), EXPO (36), EXPO (40), EXPO (48), EXPO (60), and running each model for 15 replications.
- Delivery size: We vary the delivery size to 1.25, 1.5, 2 times the original delivery size in the base model and run the model for 15 replications to obtain results.
- Total travel time: The total travel time consists of the actual travel time from one stop to the other, in addition to the loading and unloading time at each stop. As explained in the Modeling sub-section, the travel times and loading and unloading times are

calculated for each node. The total travel time in each case is used to check whether the routing exceeds the time limit of the workers' (student assistants) working shift.

Different combinations of the above iterations are also made and run in the model to get informative results. Although the parameter values change, the original setting for running the model is not modified.

The following chapter presents the results obtained from our TSP model and Arena analysis model, and the final chapter includes the conclusion and remarks.

CHAPTER FOUR: FINDINGS

As stated in Chapter 3, we first build a TSP model for obtaining a routing sequence for the delivery and pickup of loan materials without considering the delivery or pickup demand. Following this procedure is an analysis model to check the feasibility of the routing sequence by considering vehicle capacity and delivery route time constraints, using Arena.

We first present the routing sequence for the 16 campus buildings. Table 10 below summarizes the stop number and the stop name.

Table 10: Final Routing Sequence Table

Stop No.	Bldg. No.	Building Name
1	12	Math & Physics
2	5	Chemistry
3	20	Biological Science
4	54	Computer Science Building
5	45	Business Administration
6	94	Business Administration 2
7	53	CREOL
8	91	Engineering 1& 2
9	90	Health & Public Affairs 2
10	80	Health & Public Affairs1
11	87	College of Arts & Science
12	75	Communications Building
13	95	Brunett Honors College
14	18	Colbourn Hall
15	21	Education
16	14	Howard Phillips Hall
17	2	Library

The same route is visually illustrated in the following Figure 8.

Figure 8: Final Routing Sequence Diagram

The feasibility of the routing sequence is checked for exceeding the vehicle capacity when varying the pickup and delivery size. Since the pickup and delivery size at each stop may vary, some investigation is done to test the robustness of the route and the proportion of time when the capacity of the vehicle will be reached and a scheduled pickup cannot be accommodated. Additionally the feasibility of the route is also checked for exceeding the maximum route time when varying the pickup and delivery time. The pickup and delivery time for this new system is estimated and thus needs some sensitivity analysis. The total route time is constrained by the working hours in a shift (5 hours). If that time is exceeded, an additional worker and vehicle may be needed. Below we describe the approach and results from these analyses.

Pickup Size Analysis

Table 11 gives the results of varying the pickup size on the vehicle capacity. From the table, we can observe that with the expected pickup amount of Expo (20), the cumulative loads do not exceed the vehicle capacity at any of the nodes in the route. However, even a small increase in the pickup amount gives rise to overloading. For example, when the pickup amount is increased to Expo (28) and 15 simulations replications are run, five of the runs exceed the vehicle capacity, which is 33.33% of the time. An increase of 8 pounds is the equivalent 2 additional returnable since we are assuming 4 lbs /returnable. On the other extreme, when the pickup amount is increased to Expo (48), there is a 100% chance that the vehicle exceeds the capacity at one or more stops.

Table 11: Overcapacity Analysis for Varying Pickup Size

Maximum Capacity (pounds)	Vehicle Load At start (pounds)	Pickup Amount Exponential(pounds)	Delivery Amount (pounds)	No. of Reps Over Capacity (out of 15)	% of Runs Over Capacity
500	224	expo(20)	224	0	0
500	224	expo(28)	224	5	33.33%
500	224	expo(36)	224	11	73.33%
500	224	expo(40)	224	12	80%
500	224	expo(48)	224	15	100%
500	224	expo(60)	224	15	100%

This analysis shows that our routing sequence will fail to work if there is an increase in the pickup amounts provided the delivery amount does not change. A few solutions to this problem are suggested towards the end of the section.

Delivery Size Analysis

Next, we investigate the impact on the vehicle capacity of varying the delivery amount. For this analysis, the mean pickup amount is held constant at 20 pounds per stop. The delivery amount is increased from the original amount of 224 pounds to 2.0 times the original amount, or 448 pounds. Note that the vehicle load at start of the route is equal to the delivery amount. Also, the maximum increase in delivery size that we can consider cannot exceed 2.0 times the delivery size to stay below the 500 pound vehicle capacity. The complete results of the delivery amount analysis are shown in Table 12.It can be seen that varying the delivery size to 1.25, 1.50, and 1.75 times the original does not exceed the vehicle capacity within the routing sequence. However, a change in the delivery size to 2.0 times the original size produces two instances out of 15 of over capacity, which is approximately 13% of the runs.

Table 12: Overcapacity Analysis for Varying Delivery Size

Pickup Amount	**Delivery Amount**	**Vehicle Load At start**	**No. of Runs Over Capacity (out of 15)**	**% of Runs Over Capacity**
expo(20)	original	224	0	0%
expo(20)	1.25 *original	280	0	0%
expo(20)	1.50 *original	336	0	0%
expo(20)	1.75 *original	392	0	0%
expo(20)	2.00 *original	448	2	13.33%

This analysis shows that our routing sequence is fairly robust in terms of handling varying delivery sizes of up to 392 pounds.

Total Route Travel Time Analysis

The total travel time includes the actual travel time of the vehicle from one node to another in addition to the loading and unloading time at each node. The following Table 13 summarizes the total travel times for 15 replications with the original pickup size of Expo (20) and original delivery size of 224 pounds.

Table 13: Total Route Travel Times per Replication

Replication	**Total Travel Time (in minutes)**
1	350.13
2	352.22
3	339.82
4	367.71
5	336.14
6	347.72
7	355.65
8	348.21
9	336.76
10	348.07
11	345.04
12	339.26
13	350.82
14	345.44
15	334.82
Average	**346.52**

From the table, we observe that the total travel times vary from 334.82 minutes to 367.71 minutes, which is from 5.5 hours to 6.1 hours. Usually, a working shift of the deliverer (usually a student assistant) will be 5 hours without including breaks. In which case, the total delivery times lie around (if just a little over) the exact limit of the worker’s shift.

These times include the travel time, unloading, delivery, pickup and loading activities at each stop. The following Table 14 gives a sample of the arrival time, time at the stop, and the departure time for 2 replications with original pickup size of Expo (20) and original delivery size of 224 pounds. The travel time between stops is assumed to be a Triangular distribution with a mode of 4 minutes or 6 minutes depending upon the pedestrian traffic in that area. The lower bound is 3 minutes or 5 minutes and the upper bound is 6 or 7.5 minutes respectively. These times are calculated using the average speed of golf cars within the campus, which varies from 10 mph (lower bound) to 20 mph (upper bound).

Table 14: Time Detail for Each Stop for Replications 1 & 2 (in minutes)

Replication Number	Stop Number	Travel Time	Arrival Time	Time at Stop	Departure Time
1	1	5.86	5.86	19.15	25.01
1	2	5.77	30.77	9.35	40.12
1	3	5.57	45.7	8.8	54.5
1	4	7.04	61.53	8.4	69.93
1	5	6.76	76.69	23.15	99.84
1	6	5.57	105.41	19.65	125.06
1	7	5.48	130.55	11.05	141.6
1	8	4.21	145.81	13.9	159.71
1	9	3.94	163.65	29.3	192.95
1	10	3.74	196.69	39.1	235.79
1	11	5.13	240.91	9.8	250.71
1	12	5.87	256.59	15.15	271.74
1	13	4.76	276.5	9	285.5
1	14	5.78	291.28	18.65	309.93
1	15	5.21	315.15	11.28	326.42
1	16	6.58	333	10.65	343.65
1	17	6.48	350.13	0	0
2	1	5.5	5.5	20.65	26.15
2	2	6.83	32.98	9.85	42.83
2	3	7.09	49.92	11.58	61.5
2	4	5.47	66.97	11.05	78.02
2	5	7.04	85.06	21.25	106.31
2	6	6.37	112.68	16.35	129.03
2	7	4.04	133.07	12.1	145.17
2	8	3.96	149.13	13.75	162.88
2	9	4.55	167.43	31.93	199.35
2	10	4.16	203.51	29.65	233.16
2	11	3.77	236.94	7.65	244.59
2	12	4.31	248.9	24.15	273.05
2	13	4.22	277.27	9.4	286.67
2	14	5.44	292.11	18.15	310.26
2	15	6.4	316.66	13.15	329.81
2	16	5.77	335.57	10.95	346.52
2	17	5.69	352.22	0	0

The table summarizes the output from two replications, to give an indication of the load and unload times. The results for the remaining replications show similar results and have not been included. The departure time shows the time at which the vehicle departs each stop. The arrival time at the library, Stop 17, gives the total delivery time for one route. We can observe that loading and unloading time changes at each stop according to the formula given in the previous chapter. The times at the stops vary from 8 minutes to 40 minutes, as it depends upon the amount of delivery and pickup at each stop and the number of departments housed in each building (stop). Hence, loading and unloading time is a significant part of the total travel time. The efficiency of the deliverer will play a significant part in the loading and unloading time and thus the total travel time.

Pickup and Delivery Size Analysis

The analysis above addressed varying the pickup and delivery size independently. Below, we extend the above analysis to address all possible combinations of delivery and pickup sizes considered above. The results from the different combinations of the above iterations are shown in Table 15.

Table 15: Overcapacity Analysis for Delivery and Pickup Size Combinations

Pickup Amount	Delivery Amount	Current Vehicle Load	No. of Times Over Capacity (out of 15)	% of time Over Capacity
expo(28)	original	224	5	33.33%
	1.25 *original	280	5	33.33%
	1.50 *original	336	5	33.33%
	1.75 *original	392	5	33.33%
	2.00 *original	448	7	46.67%
expo(36)	original	224	11	73.33%
	1.25 *original	280	11	73.33%
	1.50 *original	336	11	73.33%
	1.75 *original	392	12	80%
	2.00 *original	448	12	80%
expo(40)	original	224	12	80%
	1.25 *original	280	12	80%
	1.50 *original	336	12	80%
	1.75 *original	392	13	86.67%
	2.00 *original	448	13	86.67%
expo(48)	original	224	15	100%
	1.25 *original	280	15	100%
	1.50 *original	336	15	100%
	1.75 *original	392	15	100%
	2.00 *original	448	15	100%
expo(60)	original	224	15	100%
	1.25 *original	280	15	100%
	1.50 *original	336	15	100%
	1.75 *original	392	15	100%
	2.00 *original	448	15	100%

It can be seen that even if there is a small change in the pickup size in addition to a small change in delivery size, the vehicle will be over its capacity 33% of the time. In the extreme case of high delivery and pickups (Expo (48) and Expo (60)), the vehicle will be over its capacity 100% of the time.

Table 16: Statistical Analysis for the Number of Stops over the Vehicle Capacity for Delivery and Pickup Size Combinations

Pickup Amount	**Delivery Amount**	**Average no. of stops over capacity** (over 15 runs)	**Standard deviation of no. of stops over capacity** (over 15 runs)
expo(20)	original	0.4	1.55
	1.25 *original	0.4	1.55
	1.50 *original	0.53	1.81
	1.75 *original	0.73	2.58
	2.00 *original	1.53	3.54
expo(28)	original	2.67	4.23
	1.25 *original	3.00	4.87
	1.50 *original	3.47	5.30
	1.75 *original	3.73	5.52
	2.00 *original	4.27	5.79
expo(36)	original	6.20	4.99
	1.25 *original	6.47	4.97
	1.50 *original	7.33	5.26
	1.75 *original	8.07	5.36
	2.00 *original	9.33	5.31
expo(40)	original	7.67	4.67
	1.25 *original	8.47	4.99
	1.50 *original	8.87	5.26
	1.75 *original	9.40	4.84
	2.00 *original	10.60	4.98
expo(48)	original	9.93	3.99
	1.25 *original	10.20	3.86
	1.50 *original	10.73	3.76
	1.75 *original	12.13	3.91
	2.00 *original	13.13	3.83
expo(60)	original	11.13	3.46
	1.25 *original	11.8	3.43
	1.50 *original	13.07	3.61
	1.75 *original	13.8	3.57
	2.00 *original	14.2	3.71

Table 17:Statistical Analysis for the Pounds over the Vehicle Capacity for Delivery and Pickup Size Combinations

Pickup Amount	Delivery Amount	Average of maximum lbs over capacity (over 15 runs)	Average of maximum no. of returnables over capacity (over 15 runs)	Standard deviation of maximum lbs over capacity (over 15 runs)	Minimum of maximum lbs over capacity (over 15 runs)	Maximum of maximum lbs over capacity (over 15 runs)	Count of no. of runs over capacity (over 15 runs)
expo(20)	original	96	24	-	96	96	1
	1.25 *original	96	24	-	96	96	1
	1.50 *original	57	14	-	17	96	2
	1.75 *original	71	18	-	46	96	2
	2.00 *original	56	14	-	6	96	4
expo(28)	original	120	30	114	2	334	6
	1.25 *original	125	31	113	2	334	6
	1.50 *original	130	33	114	2	334	6
	1.75 *original	119	30	115	2	334	7
	2.00 *original	120	30	111	2	334	8
expo(36)	original	179	45	157	43	575	12
	1.25 *original	182	46	158	43	575	12
	1.50 *original	184	46	160	43	575	12
	1.75 *original	174	44	162	7	575	13
	2.00 *original	172	43	159	32	575	14
expo(40)	original	236	59	180	21	695	13
	1.25 *original	238	60	180	21	695	13
	1.50 *original	240	60	182	21	695	13
	1.75 *original	228	57	185	21	695	14
	2.00 *original	237	59	181	51	695	14
expo(48)	original	338	85	235	7	934	15
	1.25 *original	338	85	235	7	934	15
	1.50 *original	340	85	236	7	934	15
	1.75 *original	343	86	236	7	934	15
	2.00 *original	348	87	234	7	934	15
expo(60)	original	550	138	294	136	1295	15
	1.25 *original	550	138	294	136	1295	15
	1.50 *original	550	138	294	136	1295	15
	1.75 *original	551	138	294	136	1295	15
	2.00 *original	553	138	295	136	1295	15

Table 16 above summarizes additional statistical facts relating to the analysis of the number of stops that exceeds the vehicle capacity for different delivery and pickup size combinations. The average number of stops at which the vehicle is over capacity increases gradually from 0.4 to 14.2 as the pickup size increases, which is similar to the analysis in Table 15. Also, the standard deviation of the number of stops at which the vehicle is over capacity increases along with the increase in delivery size (with pickup size remaining the same in each case). An interesting observation here is that for extreme pickup sizes of expo (48) and expo (60), the standard deviation of the number of stops at which the vehicle is over capacity does not change substantially, and its value remains to be almost the same.

Table 17 above shows the analysis of the maximum pounds exceeding the vehicle capacity for different delivery and pickup size combinations. This is, of course, only valid for routes that exceed the vehicle capacity. To read this table for example, the analysis with the pickup amount exponential with a mean of 28 pounds and the original delivery amount, there are 6 runs that are over capacity. For the routes that are over capacity, the maximum of the pounds over will be between 2 and 334 pounds, with the average being 120 pounds and the standard deviation being 114 pounds. The pounds above capacity are converted to returnable items by dividing by the average 4 pounds per returnable. The standard deviation of the maximum number of pounds over capacity shows a trend similar to that for the number of stops at which the vehicle is over capacity, i.e., for extreme pickup amounts, the standard deviation remains almost the same.

This analysis evokes concern regarding the feasibility of our routing sequence in practice. Some alternative solutions for preventing this problem are listed below:

1. Increasing the vehicle capacity
2. Dividing the single route into two separate routes

We discuss these two alternatives in more detail below.

Using a vehicle with higher payload, for example a golf car with a payload capacity of 800 to1000 pounds, will solve the problem of overloading. There is not a significant difference in the cost of a 500 pound capacity vehicle and 1000 pound capacity vehicle, which is around $500 to $1000 depending upon the vendor. Table 16 below shows the results from using a vehicle with payload capacity of 1000 pounds.

Table 18: Varying Vehicle Capacity

Pickup Amount	**Delivery Amount**	**Current Vehicle Load**	**No. of Times Over Capacity (out of 15)**	**% of time Over Capacity**
expo(20)	Original	224	0	0%
	2.00 *original	448	0	0%
expo(28)	Original	224	0	0%
	1.50 *original	336	0	0%
	2.00 *original	448	0	0%
expo(48)	Original	224	3	20%
	1.50 *original	336	3	20%
	2.00 *original	448	3	20%
expo(60)	Original	224	6	40%
	1.50 *original	336	6	40%
	2.00 *original	448	6	40%

It is evident from the table above that increasing the vehicle capacity substantially reduces the number of times the vehicle will be over its capacity in the current routing sequence. For example, in extreme cases of pickups (Expo (48) and Expo (60)) and delivery (448 pounds), the vehicle will be over its capacity only 20% and 40% of the time, respectively. Hence, this alternative can prove to be beneficial.

Dividing the route into two routes instead of one is another good option which can be implemented for our problem to reduce chances of overloading as well reducing the total travel time. In order to determine two routes, we first cluster the nodes into two groups depending on their geographical locations and delivery amounts. The two clusters are shown in Table 17 below.

Table 19: Route Clusters

Cluster 1		Cluster 2	
Building No.	**Building**	**Building No.**	**Building**
2	Library	2	Library
20	Biological Science	21	Education
94	Business Admn 2	87	College of Arts & Science
45	Business Admn	18	Colbourn Hall
91	Engineering 1& 2	14	Howard Phillips Hall
80	Health & Public Affairs1	95	Brunett Honors College
90	Health & Public Affairs 2	75	Communications Building
53	CREOL	5	Chemistry
54	Computer Science Building	12	Math & Physics

Next, we determine the routing sequence for each of the two clusters using the previously developed TSP formulation, using OPL Studio software. The routing sequences obtained from this formulation are shown in Table 18.

Table 20: Two Routes Routing Sequence

Route 1		Route 2	
Building No.	**Building**	**Building No.**	**Building**
2	Library	2	Library
20	Biological Science	12	Math & Physics
94	Business Admn 2	5	Chemistry
53	CREOL	95	Brunett Honors College
90	Health & Public Affairs 2	87	College of Arts & Science
80	Health & Public Affairs1	75	Communications Building
91	Engineering 1& 2	18	Colbourn Hall
45	Business Admn	21	Education
54	Computer Science Building	14	Howard Phillips Hall
2	Library	2	Library

After obtaining the routing sequence, an analysis similar to the previous one follows. The feasibility of both the routes is checked by varying the pickup and delivery amounts and total travel time. The delivery amounts for each route would differ according to the delivery size of the included nodes. Tables 19 and 20 below show this analysis for both routes.

Table 21: Overcapacity Analysis for Route 1

Pickup Amount	Delivery Amount	Current Vehicle Load	No. of Reps Over Capacity (out of 15)	% of time Over Capacity
expo(20)	Original	164	0	0%
	1.50 *original	246	0	0%
	2.00 *original	328	0	0%
expo(28)	original	164	0	0%
	1.50 *original	246	0	0%
	2.00 *original	328	1	6.67%
expo(36)	original	164	0	0%
	1.50 *original	246	0	0%
	2.00 *original	328	0	0%
expo(40)	original	164	1	6.67%
	1.50 *original	246	1	6.67%
	2.00 *original	328	1	6.67%
expo(48)	original	164	3	20%
	1.50 *original	246	3	20%
	2.00 *original	328	3	20%
expo(60)	original	164	6	40%
	1.50 *original	246	6	40%
	2.00 *original	328	7	46.67%

Table 22: Overcapacity Analysis for Route 2

Pickup Amount	Delivery Amount	Current Vehicle Load	No. of Reps Over Capacity (out of 15)	% of Time Over Capacity
expo(20)	original	60	0	0%
	1.50 *original	90	0	0%
	2.00 *original	120	0	0%
expo(28)	original	60	0	0%
	1.50 *original	90	0	0%
	2.00 *original	120	0	0%
expo(36)	original	60	0	0%
	1.50 *original	90	0	0%
	2.00 *original	120	0	0%
expo(40)	original	60	0	0%
	1.50 *original	90	0	0%
	2.00 *original	120	1	6.67%
expo(48)	original	60	0	0%
	1.50 *original	90	0	0%
	2.00 *original	120	3	20%
expo(60)	original	60	0	0%
	1.50 *original	90	6	40%
	2.00 *original	120	6	40%

From the tables, we can conclude that compared to our previous single route, there is substantially less chance for the vehicle to become over its capacity using two routes. If used, these routes lead to overloading only in extreme cases of very high pickups and deliveries, which is only around 40% of the time, compared to 100% in the case of the single route. Hence two routes are beneficial in terms of lessening chances of overloading.

Table 23: Total Travel Times for Route 1 and Route 2

Replication	**Total travel Time (in minutes)**	
	Route1	**Route2**
1	168.64	146.61
2	179.72	150.77
3	169.17	144.10
4	184.33	151.42
5	168.12	138.54
6	172.21	147.32
7	181.41	150.23
8	191.73	165.75
9	167.67	142.95
10	166.65	144.31
11	173.28	145.63
12	169.30	143.04
13	169.84	142.99
14	165.19	137.98
15	162.02	136.92
Average	**172.62**	**145.90**

Table 21 summarizes the total travel time for Route 1 and 2. The travel times for Route 1 vary from 137 minutes to 165 minutes, which is 2.3 to 2.7 hours. Route 2 times varies from 162 minutes to 191.73 minutes, which is 2.7 to 3.2 hours. Combined the two routes would equate to between 5.0 and 5.9. Individually, these times are much lower as compared to the total travel times of 5.5 hours to 6.1 hours for one single route. Thus, two routes are beneficial in terms of timesavings as well as flexibility of delivery workers' shifts. The library can assign two delivery workers working different shifts and using the same vehicle for delivery and pickups. Of course, this would incur some additional costs, but it will be advantageous in the long run, when the system becomes popular and delivery and pickup amounts increase.

In the next chapter, we present our conclusions and recommendations over this study and discuss implications for future research from this study.

CHAPTER FIVE: CONCLUSION

Overall, within this study we develop a routing sequence for the purpose of delivering documents to various departments within the UCF main campus to improve interlibrary loan services. We build a TSP model to obtain a route and then evaluated the feasibility of the model with respect to vehicle capacity by varying demand (delivery and pickup). We simulate the demand over the route in order to evaluate the risk of the route becoming infeasible. We also evaluate whether the total travel time is within the deliverer's working shift and how significant the loading and unloading time is with respect to the total travel time.

Conclusions and Recommendations

In the end, our route proved successful for the original delivery and pickup amounts. We were able to analyze the route with respect to varying delivery and pickup sizes to check its feasibility. We found that the route is more sensitive towards the pickup size than delivery size because of the large variance associated with the assumption that the pickups are distributed exponentially. Even a small increase in the mean pickup size leads to overloading within the route 33% of the time. As expected, the chances of overloading increases with higher mean pickup amounts. On the other hand, in case of increasing the delivery size, overloading occurs only in the extreme case of delivery size being twice the original amount or when pickup size is increased in conjunction with delivery size. We also found that loading and unloading time significantly influences the total travel time for the complete route. Delivery and pickup routing with the original model takes around 5 to 6 hours depending on the amount of pickups and deliveries.

In order to make our model more robust in all cases, including extreme cases, we recommend using a vehicle with a higher payload capacity of around 1000 pounds and using two routes instead of one. These recommendations will help reduce the chances of overloading and provide flexibility in terms of workers' shifts, with only small additional costs

In conclusion, our model helps to fulfill the goals of the UCF library as well as cater to UCF's research needs. The library will be able to improve its customer service by increasing the number of users due to improved customer convenience, reduced effort, and through positive feedback from its current customers. It will also help the library to adapt to increased university demand and provide the faculty with fast and easy access to publications in an attempt to support the university's research base. Above all, it would make UCF one of the premiere institutions in Florida with provision of such a service.

Contributions and Future Research Directions

Our effort to customize a VRP for the needs of the ILL/DDS system of UCF is an asset to the institution while providing another successful and practical implementation of the well-known theoretical concept of VRP. The feasibility analysis of the route using computer simulation accounts for the variability in demand and at the same time provides a route that is capable of handling future growth in demand and daily variations without deviating from the planned route. Incorporating unique features like varying demand and uncertain loading and unloading time to provide a robust route and minimize the effects of infeasibility are a contribution to the research of the VRP.

However, this study is limited in terms of the area covered for designing UCF library's document delivery service. A similar study can be done to incorporate departments affiliated to UCF located in the Research Park at UCF. Due to a different geographical layout of nodes lying in the Research Park, we were unable to include them in this study. However, it would be very beneficial for the UCF library to extend its document delivery service to the Research Park, owing to the extensive research conducted there.

On a larger scale, the study can be extended to UCF's 13 remote campuses lying all around the Central Florida region, thereby fulfilling the UCF library's goal of improving customer service. Replicating the service for graduate students and research assistants with offices on campus would also be a good future development to this study.

APPENDIX A

OPL CODE

Model File

```
int nbfromnode =...;
int nbtonode =...;
int capacity =...;

range
fromnode 1..nbfromnode,
tonode 1..nbtonode;

//Parameters
SheetConnection sheet("C:\Documents and Settings\Kartik  Patel\Desktop\THESIS\internodal distances_17.xls");
float distance[1..nbfromnode, 1..nbtonode] from SheetRead(sheet, "B22: R38");

//Variables
var int route[fromnode,tonode] in 0..1;

//Objective Fn
minimize
    sum(i in fromnode,j in tonode) (distance[i,j] * route[i,j])

//Constraints
subject to {
    forall (j in tonode)
    sum (i in fromnode) route[i,j] = 1;
    forall (i in fromnode)
    sum (j in tonode) route[i,j] = 1;


//Subtour elimination constraints
route[7,8]  + route[8,7]  <=1;
route[9,13] + route[13,9] <=1;
route[1,17] + route[17,1] <=1;
route[15,4] + route[4,15] <=1;
route[14,5] + route[5,14] <=1;
route[9,13] + route[13,9] <=1;
route[2,11] + route[11,2] <=1;
route[3,16] + route[16,3] <=1;
 route[6,15] + route[15,6] <=1;
 route[10,12] + route[12,10] <=1;

 route[6,8]  + route[8,7] + route[7,6] + route[8,6] + route[7,8] + route[6,7] <=2;
 route[2,10] + route[10,11] + route[11,2] + route[10,2] + route[11,10] + route[2,11] <=2;
 route[9,12] + route[12,13] + route[13,9] + route[12,9] + route[13,12] + route[9,13] <=2;
```

route[8,7] + route[7,6] + route[6,15] + route[15,8] + route[7,8] + route[6,7] + route[15,6] + route[8,15] <= 3;
route[7,8] + route[8,6] + route[6,15] + route[15,7] + route[8,7] + route[6,8] + route[15,6] + route[7,15] <= 3;

route[1,14] + route[14,5] + route[5,4] + route[4,3] + route[3,16] + route[16,17] + route[17,1] + route[14,1] + route[5,14] + route[4,5] + route[3,4] + route[16,3] + route[17,16] + route[1,17] <=6;

};

Data File

nbfromnode = 17;
nbtonode = 17;
capacity = 500;

APPENDIX B
AVERAGE DAILY DEMAND FOR DEPARTMENTS IN BUILDINGS

Bldg no.	Building	Departments	Avg daily demand (number)	Avg daily demand *4 pounds
21	Education	Child, Family & Community Sciences, Department Of	6	24
		Clinical Experiences	-	
		Community Counseling Clinic	-	
		Curriculum Materials Center (Cmc)	-	
		Education, College Of	-	
		Educational Research, Technology & Leadership, Department Of	-	
		Educational Studies	-	
		Lockheed Martin/UCF Academy For Mathematics & Sciences	-	
		Minority Programs In Education (Mpie)	-	
		Teaching And Learning Principles, Department Of	1	4
			7	**28**
20	Biological Sciences	Biology dept	2	8
		Burnett College Of Biomedical Sciences	-	-
			2	**8**
94	BA 2	Devos Sport Business Management	1	4
		Economics, Department Of	-	-
		Marketing, Department Of	-	-
			1	**4**
45	BA	Accounting, Kenneth G. Dixon School Of	-	-
		Business Administration, College Of	1	4
		Finance Department	-	-
			1	**4**
40 & 91	Engg 1 & 2	Electrical & Computer Engineering, Department Of	-	-
		Engineering	7	28
		Mechanical, Materials & Aerospace Engineering	-	-
		Civil & Environmental Engineering	-	-
		Engineering & Computer Science, College Of	-	-
		Industrial Engineering & Management Systems	-	-
			7	**28**
80	HPA 1	Criminal Justice & Legal Studies	1	4
		Eastern Europe Linkage Institute	-	-
		Florida Canada Linkage Institute	-	-
		Health & Public Affairs, College Of	1	4
		Health Professions	-	-
		Nursing, School Of	3	12
		Physical Therapy Program	-	-
			5	**20**
90	HPA 2	Athletic Training	-	-
		Cardiopulmonary Sciences Program	-	-
		Communicative Disorders	1	4
		Medical Laboratory Science Program	-	-
		Molecular Biology & Microbiology	1	4
		Public Administration	1	4

		Radiological Sciences	-	-
			3	**12**
87	CAS	Arts & Sciences, College Of	1	4
			1	**4**
18	Colbourn Hall	English Department	3	12
		Foreign Languages & Literatures	4	16
		History Department	3	12
		Judaic Studies Program	-	-
		Liberal And Interdisciplinary Studies	-	-
		Music Department, UCF	1	4
		Philosophy	-	-
		Political Science	1	4
			12	**48**
14	Howard Phillips Hall	Psychology	8	32
		Sociology & Anthropology	3	12
			11	**44**
95	BHC	Honors College, The Burnett	**1**	**4**
75	Communications	Communication, Nicholson School Of	1	4
		Film & Digital Media, School Of	-	-
			1	**4**
54	Computer Science	Computer Science, School Of	1	4
			1	**4**
53	CREOL	Creol	1	4
		Florida Photonics Center Of Excellence	-	-
		Optics And Photonics, College Of	-	-
			1	**4**
5	Chemistry	Chemistry	1	4
			1	**4**
12	Math & Physics	Mathematics , Department Of	1	4
		Physics	1	4
			1	**8**
		Total daily delivery	**56**	**224**

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