Washington Post Distribution &Fleet Analysis

Final Report
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Table of Contents

1 Executive Summary

1.1 Purpose

Due to a decline in the number of Washington Post newspaper subscriptions, there is need to identify efficiency gains and cost savings wherever possible. Successful delivery of Washington Post Daily and Sunday newspaper products depends on the interaction of the Washington Post Circulation Department's (WPCD) transportation fleet to ship newspaper product that is produced at the Washington Post's Springfield, Virginia production plant to their twenty-seven storage warehouses located across the Virginia, Maryland, and D.C. area. The WPCD is concerned with reducing costs through optimizing the trucking routes that move the product from production to distribution, optimizing the mix of types of trucks they use in their fleet to move the products, and optimizing the schedule for driver's to eliminate paying for unused labor. Assessments of the driver schedules and the fleet mix are largely dependent on the method for scheduling and routing the trucks to move the product, therefore the primary priority was to create a model to route the trucks dynamically based on the amount of product, production time, available trucks, and distribution center demands all while reducing overall cost. As a secondary benefit of creating the truck scheduling model, we propose a solution for the fleet mix assessment that needs to be performed after the truck scheduling model has been implemented by WPCD. This report will not consider the Driver Scheduling problem. The driver schedules are published in advance of knowing the number of trucks and routes that would be needed to distribute the product. The solution involves a predictive model for the number of products, the truck routing model to predict the routes and a driver assignment problem. The additional models and processes are beyond the scope of this project.

1.2 Approach

Given the complexities of the system of interest, it was very important that the Team obtain an in depth understanding of the system and processes that are currently in place at the WPCD. Our approach for process analysis has been be to work closely with our customer point of contact (POC) to develop an understanding of the WPCD's current processes and current process limitations, and to collect historical data from the WPCD transportation database. Beyond documenting the present system behavior, it has also been instrumental for us to document the needs of the Washington Post (WP) customer with respect to the product delivery system. By constructing a high level schedule representation of the system behavior based on each of the WP product types for a one week shipment, we were able to set the foundation for our truck routing model. The truck routing model is formulated as a Time-Space network Integer Program. This formulation allows us to model the movements of product as it's produced through the network with constrained availability of trucks while reducing the cost. The model accepts estimated daily product volume and warehouse demands. The model combines shipments into one route that serves multiple distribution centers where it is feasible and cost effective to do so. The fleet mix model uses the truck routing schedule as an engine. A linear regression on the data that was provided by the WPCD was performed to project the product demand in the future. The projected number of pallets is used as an input to the truck routing model. Additionally, the number of trucks available is left unconstrained. The routing solution will use the optimal number of trucks. Using this approach after the implementation of the routing model will allow the WPCD to assess their leasing needs as truck leases expire and need to be renegotiated. They can also use this approach to assess their needs for peak demands like the increased volume of advertisements during the holiday season.

1.3 Results

In all test cases we were able to find solutions that were dramatically better than shipping according to the “spoke” model (i.e. routes only from the production plant to the distribution centers and back). Considering only gas and leasing costs, our model shows savings on average of around $300 per day. Also, the solutions show a drop in total driving mileage around 400 to 500 miles per day. Our solutions also increase the utilization rate of trucks (i.e. shipping the same number of pallets with fewer trucks). While labor costs were not taken into consideration in our model due to the driver scheduling system The Washington Post already has in place, our results suggest that dynamically routing trucks generates significant savings in labor as well.

Gas and leasing cost savings come from efficiently and dynamically “bundling” orders together depending on how many pallets are needed at each distribution center. Given that there is sufficient time, it is almost always cheaper to have a single truck go to two different distribution centers than have two trucks going to each one separately. This bundling however is not obvious. In analyzing routing output from our model for three test cases, we found over forty instances of multi-distribution center tours and not one was ever repeated. The optimal routing will change from day to day depending on demand and any static system of scheduling will most likely be suboptimal.

1.4 Recommendations

Our team has identified significant cost savings for The Washington Post by efficiently and dynamically scheduling truck routes based on daily demands. The team has developed a proof of concept model that takes daily demand input and dynamically schedules truck routes to minimize fuel and leasing costs. The model employs a user-friendly Excel based front-end which interfaces with an integer programming model written in MPL and ultimately solved using the CPLEX engine.

While the team wrote the code for the front-end and model, CPLEX is a commercial grade optimization solver costing around $10,000 for a single license. Despite the initial cost of the software, we believe that our model identifies enough savings to justify implementation. In all test cases we were able to find solutions saving between $200 and $300 per day and around 400 to 500 driving miles. These savings alone justify the cost of a CPLEX license. In addition, our analysis does not include possibly the biggest driver of cost savings, labor. In all test cases our model produced solutions that increased the percentage of time that trucks remained at the production plant. This is an indicator that if a dynamic routing system is implemented, fewer trucks, and thus fewer drivers, will be needed per day.

Should The Washington Post decide to implement a dynamic truck routing system, we recommend that it be based on the time-space network framework. The mathematical formulation is easy to implement and straight forward to understand. The bulk of the work for implementing a time-space network is in the network generation phase before anything is sent to the optimization solver.

Unless very powerful computing platforms such as server clusters are used, the network containing all feasible solutions is simply too big to handle. Generating the feasible arcs in the network in a controlled, intelligent way is critical to the model producing good solutions.

2 Overview

2.1 Introduction

In the fall of 2010 and spring of 2011, the Washington Post requested graduate students from the Department of Systems Engineering and Operations Research at George Mason University (GMU) to assist their Springfield, Virginia plant with determining an efficient method to produce cost savings in their shipping and receiving operations. The GMU team performed data collection and process evaluation, resulting in recommendations for efficiency gain which have since been implemented in the Shipping and Receiving Department.

This year, the client would like to expand the problem scope to determine an efficient method to produce cost savings within their Circulation Department. The Washington Post Circulation Department (WPCD) is looking to find the most cost effective truck run schedule, the most efficient truck fleet combination, the most cost effective driver schedule, and the optimal driver staffing plan needed to deliver Daily and Sunday papers to their twenty-seven warehouses to support on time delivery to residences in the Washington, D.C. area.

2.2 Stakeholder Description

The following stakeholders have been identified:

Transportation Division, Julio Pascual – Manager
Circulation Operations, Jim Dean Jr. – Director

2.3 Problem Statement

For the purpose of shipping newspaper products from their Springfield, Virginia production plant to their twenty-seven warehouses, the Washington Post's Daily and Sunday packages are broken into multiple types of delivery products. Volume of each product type is variable and subject to change based on inserts such as fliers, coupons, magazines, etc. Expected volume of each product type is not known until roughly the night before the scheduled day of shipment. Given that constraint, the Washington Post Circulation Department develops a weekly driver schedule the Friday before the next work week, which runs from Sunday to Saturday, however individual daily truck runs are not determined until the night before the next day's planned shipment.

The WPCD Transportation Fleet is made up of both cargo trucks and licensed drivers. The current truck fleet consists of straight trucks, tractors with trailers, 32' trailers, 36' trailers, 48' trailers, and 53' trailers. The Washington Post leases all trucks in its fleet from one of two companies; Penske provides straight trucks and tractor trailers, and its sister company Robinson Terminal Warehouse provides additional tractor trailers. Trucks are typically leased on a 7 year term, with term end dates varying across the fleet. The Washington Post's current driver fleet is comprised of 30 full time and 30 part time drivers, 55 of which hold a Class A Commercial Drivers License (CDL) and 5 hold a Class B CDL. All trucks in the current fleet require drivers to have a Commercial Drivers License.

Successful delivery of Washington Post Daily and Sunday newspaper products depends on the interaction of the WPCD truck fleet and the WPCD driver fleet to transport newspaper product that is produced at the Washington Post's Springfield, Virginia production plant to their twenty-seven storage warehouses located across the Virginia, Maryland, and D.C. area. [see **FIGURE 1**]

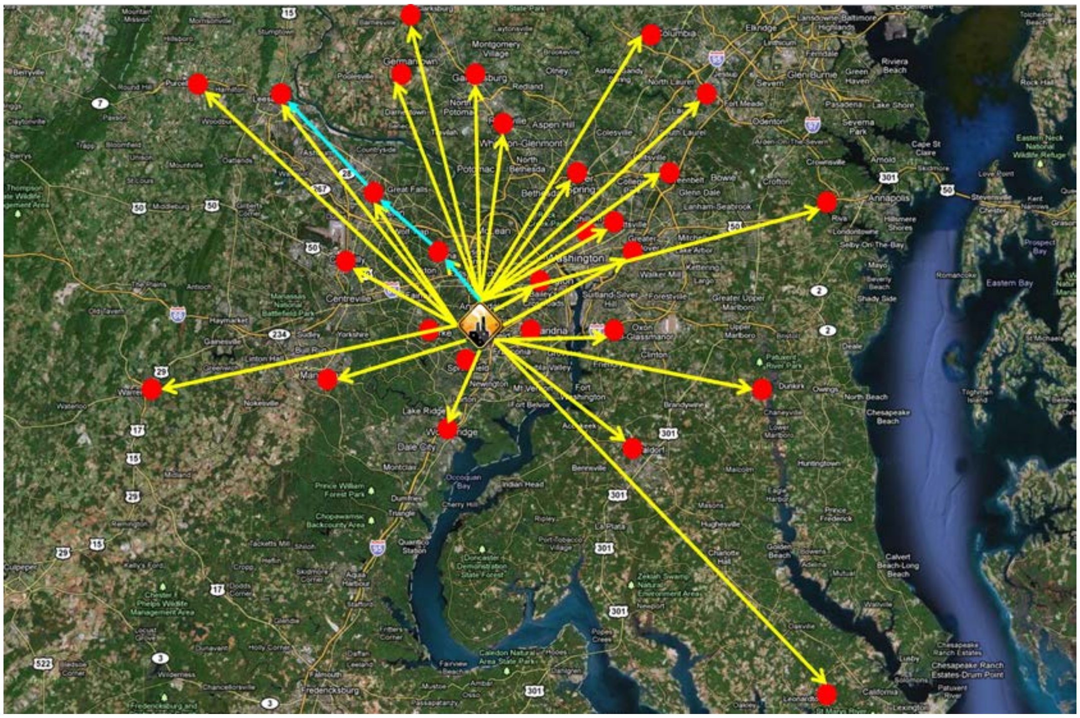


FIGURE 1

2.4 Statement of Need

The team objective is to maximize the efficiency of the truck run schedule in the Circulations Department at the Washington Post's Springfield, Virginia plant. The efficiencies that are gained are intended to set the basis for future work in reducing the operating costs associated with fleet makeup (truck rental fees) and driver staffing plan (employee labor rates).

The Washington Post's Springfield, Virginia facility ships multiple product types including Daily Paper Advanced Runs, Daily Paper Headsheets, Sunday Packages, Sunday Front Page Headsheets, Sunday Advanced Package #1 and Sunday Advanced Package #2. The time which each of these product types is available for shipment, and the time which products of each of these types is required to be at the warehouses varies and is dependent on product type.

The scope of this project deals with truck schedules, including truck type, needed to facilitate the movement of pallets of the product types identified above from the Springfield, Virginia production facility to the twenty-seven warehouses to enable timely delivery of Daily and Sunday papers to resident subscribers.

3 Process Analysis

3.1 System/Process Analysis

Given the complexities of the system of interest, it was very important that the Team obtain an in depth understanding of the system and processes that are currently in place at the Washington Post Circulation Department. The system is, and must always be able to sufficiently transport pallets of various types of product from the Springfield, Virginia production facility to twenty-seven warehouses in the Washington, D.C. area.

Currently, the process used to facilitate timely transportation of products produced at the Springfield, Virginia plant involves numerous product types, changing product volumes, varying delivery need times, multiple truck types, numerous routes, and a driver staff qualified with two different types of commercial driver licenses. These components interact throughout the twenty-eight physical facilities in the transportation system, based on extensive scheduling of both truck routes and driver shifts.

Our approach for process analysis has been be to work closely with our customer point of contact (POC) to develop an understanding of the WPCD's current processes and current process limitations. It was crucial that these processes be documented and reviewed by the customer to ensure that our team had a correct and consistent understanding of the current system behavior.

Beyond documenting the present system behavior, it has also been instrumental for us to document the needs of the Washington Post customer with respect to the product delivery system. In this case, the WPCD system's needs are best understood by creating a descriptive diagram distinguished by product type, since the business rules for the system vary if the pallets being delivered are made up of Daily Paper Advance Run product, Daily Paper Headsheet product, Sunday Package product, Sunday Front Page product, Sunday Advanced #1 product, or Sunday Advanced #2 product. Understanding these business rules by constructing a high-level schedule representation of the system behavior based on each of these product types for a one week shipment has helped to set the foundation for our model.

3.2 System Data Collection and Analysis

To perform a thorough analysis, we have acquired quantitative data for each component of our system that was defined during our process analysis (e.g. truck types, product types, routes, etc.). Conveniently, the Washington Post has implemented a comprehensive data tracking system and has been able to provide historical data on things such as product volume and transportation times for a two month period.

Besides obtaining and analyzing this data, we have elicited additional information from our Washington Post POC, including priorities, preferences, and issues that may not been identified through historical data analysis alone. The GMU Team also took the opportunity to visit the Springfield, Virginia production facility and view the WPCD system in action, which helped us to better understand the current shipment processes, and inputs and outputs of the WPCD Management Team's current scheduling process.

Once this data was collected, our team then used the data to conduct analysis to look for holes or areas that lacked definition within the system and used an iterative approach to collect additional data to continue to document the system's structure and behavior. Through this process, we were able to obtain descriptive statistics for each of the components of the system. We then leveraged this information to exploit our quantitative and qualitative understanding of the product transportation system to ultimately determine what type of model would be best to use to facilitate fleet schedule decisions.

4 Requirements

4.1 Project Requirements

2.1.1 Our Team shall document the functional system requirements for the current Washington Post Circulations Department (WPCD) system.

2.1.2 Our Team shall develop a Concept of Operations.

2.1.3 Our Team shall perform a trade analysis of alternative modeling techniques.

2.1.4 Our Team shall perform model output analysis to make process improvement recommendations to the Washington Post customer.

2.1.5 Our Team shall complete a Project Proposal on 9/22/2011.

2.1.6 Our Team shall provide a one page status report on 10/13/2011.

2.1.7 Our Team shall provide an In Progress Review Report on 10/20/2011.

2.1.8 Our Team shall provide a final report on 12/1/2011.

2.1.9 Our Team shall provide a dynamic system model to the Washington Post customer on 12/1/2011.

2.1.10 Our Team shall provide a final presentation on 12/8/2011.

2.1.11 Our Team shall develop a website to publish all project documentations and results.

4.2 Functional Requirements

2.1.12 The model shall be executable with a front-end software package that is currently used by the Washington Post customer.

2.1.13 The model shall allow users to manipulate input parameters.

2.1.14 The model shall be able to accept a twenty-four hour data set, comprised of truck fleet parameters, route information, and projected product volumes by product type.

2.1.15 The model shall support dynamic updates to truck fleet mix parameters.

2.1.16 The model shall support dynamic updates to product volumes for all six product types shipped by the Washington Post Springfield production facility.

2.1.17 The model shall determine a twenty-four hour delivery schedule that optimizes cost given a constrained fleet mix.

2.1.18 The model shall aid in determining the cost benefit of varying the fleet mix.

4.3 Performance Requirements

2.1.19 The model shall support exactly one user at any given time.

2.1.20 The model shall handle a maximum of twenty-four hours of projected product volume data.

2.1.21 The model shall handle manipulation of truck fleet parameter data.

2.1.22 The model shall handle manipulation of facility route projected times.

2.1.23 The model shall handle manipulation of facility route projected mileage.

5 System Description

5.1 Purpose and Viewpoint

The purpose of the Washington Post Circulations Department (WPCD) System at the Washington Post's Springfield, Virginia plant is to provide the Washington Post the ability to facilitate the movement of pallets of various product types from the Springfield, Virginia production facility to twenty-seven warehouses in the Virginia, Maryland, D.C. area to enable timely delivery of Daily and Sunday papers to resident subscribers.

This system description will be developed from the point of view of the Circulations Department's Transportation Manager, who is looking to find the most cost effective truck run schedule, the most efficient truck fleet combination, the most cost effective driver schedule, and the optimal driver staffing plan needed to deliver Daily and Sunday papers to their twenty-seven warehouses to support on time delivery to residences in the Washington, D.C. area.

5.2 Vision

With an annual decreasing trend to the amount of Washington Post subscriptions, it is critical that the Washington Post begin to focus on system efficiency in order to operate in the most cost effective way possible. This realization has resulted in the vision of a capability to enable the Circulations Department management team to make efficient truck and driver scheduling decisions based on predicted product volume for the coming workweek.

The near-term goal is for the WPCD management team to find the most cost effective truck run schedule, and the most cost effective driver schedule as they perform their scheduling tasks on a weekly and daily basis to schedule transport of Daily and Sunday papers to support on time delivery to residences in the Washington, D.C. area. Ultimately, the WPCD management team would additionally like to determine the most efficient truck fleet combination, and the optimal driver staffing plan required to support operations.

The ability to determine a means of producing a more cost effective weekly schedule with an emphasis on daily truck routes, and eventually the most cost effective truck and driver fleet combination, is dependent on a clear understanding of the current Circulations System architecture. Because the Washington Post Circulations Department system is so complex, it is essential for the George Mason University (GMU) Systems Engineering and Operations Research (SEOR) Team to understand and capture the system's structural and behavioral relationships. This first goal of the GMU Team was to clearly document the current state of the WPCD system in order for it to be possible to then analyze potential efficiency gains for the WPCD system.

5.3 Operational Concept

The Washington Post Circulations Department system provides the Washington Post the capability to facilitate the movement of pallets of various product types from the Springfield, Virginia production facility to twenty-seven warehouses in the Virginia, Maryland, and D.C. area. The system receives inputs from the Washington Post Production Department on a daily basis which indicate the amount of expected volume of product that is planned to be produced for distribution during a given day. The WPCD management team uses this information to produce truck and driver schedules needed to facilitate transportation of products from the Springfield, Virginia production facility to warehouses dispersed throughout the region. The high level truck and driver schedule is set the week before a given production week, whereas the detailed daily truck run schedule is set the night before a given workday. Multiple product types dictate timing constraints that, along with varying pallet volume, make for a complex scheduling process. The Washington Post truck fleet, made up of tractor trailers and straight trucks rented from two different truck rental companies then execute per the derived schedule to transport product from the production facility to the warehouses as demand requires. Personnel on the Washington Post driver staff perform the task of driving these trucks as defined by the system's schedule. The process of scheduling and product distribution should be executed as efficiently as possible.

5.4 OV-1: High-Level Operational Concept Graphic

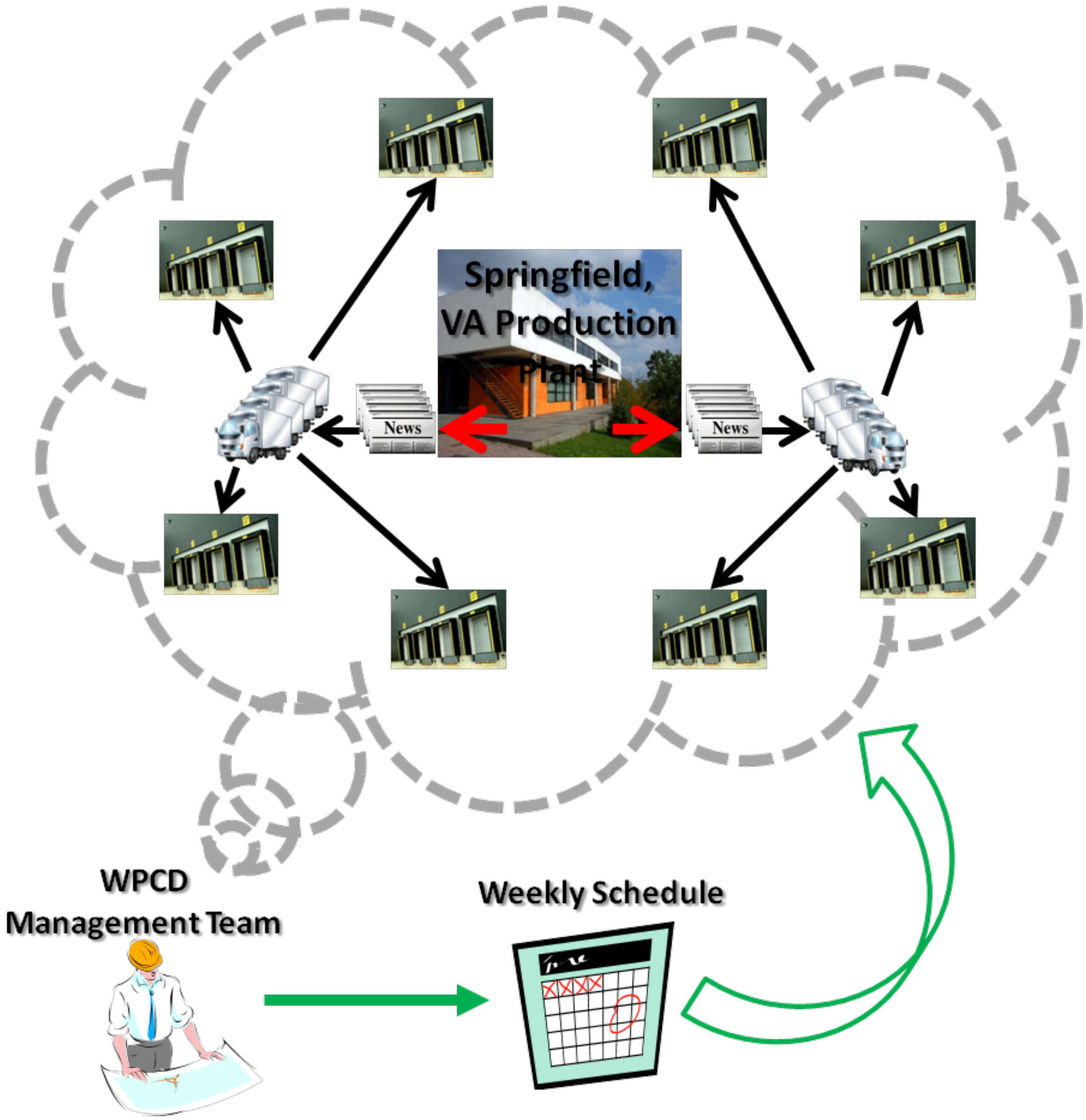


FIGURE 2

5.5 System Functional Requirements

FR-1 The Washington Post Circulations Department (WPCD) System shall transport Daily and Sunday Paper Product to a maximum of twenty-seven pre-determined warehouse locations.

FR-2 The Washington Post Circulations Department (WPCD) System shall transport Daily and Sunday Paper Product within timing constraints as determined by product demand.

FR-3 The Washington Post Circulations Department System shall execute in accordance with daily driver and truck schedules, as established by the WPCD Management Team.

FR-4 In the event of a cargo truck failure, the Washington Post Circulations Department (WPCD) System shall be capable of obtaining, within one hour of truck failure, a replacement truck of equal or greater capacity.

FR-5 The Washington Post Circulations Department (WPCD) System Schedule shall support fluctuating product volumes as determined by the Washington Post Production Facility (WPPF).

FR-6 The Washington Post Circulations Department (WPCD) System shall support routing of specialized product type (e.g. zone specific advertising) to appropriate warehouse locations as required.

FR-7 The Washington Post Circulations Department (WPCD) System shall have continual access to a fleet of cargo trucks to support Daily and Sunday Paper Product transport requirements.

FR-8 The Washington Post Circulations Department (WPCD) System shall have continual access to a staff of adequately licensed drivers to operate cargo trucks to support Daily and Sunday Paper Product transport requirements.

5.6 System Structure

The Washington Post Circulations Department system is comprised of many moving parts. At a high level, the WPCD schedule is at the heart of the system. This schedule, made up of the driver schedule as well as the truck schedule, is derived by the management team based on predicted weekly and daily newspaper product production volumes and product demand at the various Washington Post warehouses. The schedule drives the movement and interaction of system parts. These components include the Daily and Sunday newspaper products, as well as the drivers and trucks that make up the Washington Post transportation fleet. [see **FIGURE 3**]

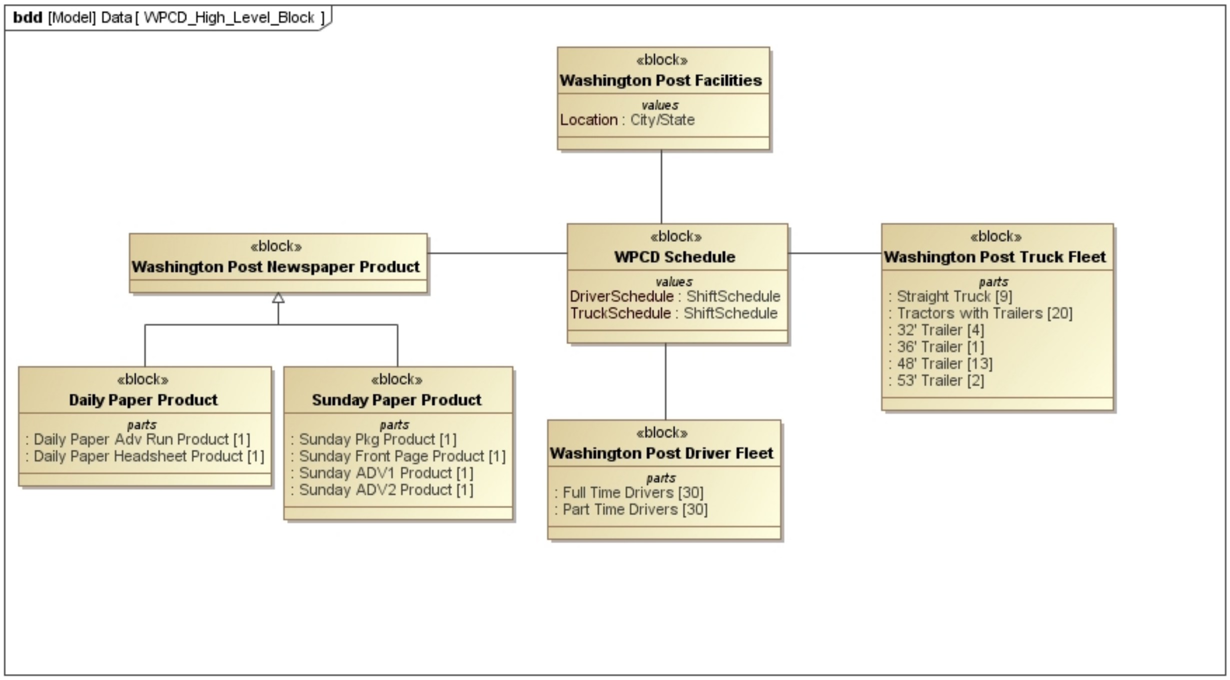


FIGURE 3

The facilities that are a part of the Washington Post Circulations Department consist of the Springfield, Virginia production plant and twenty-seven storage warehouses that are dispersed throughout the Washington, D.C., Maryland, and Virginia area. Schedule planning is heavily dependent not only on product demand at the assorted warehouse locations, but also on the distance between the various facilities. The route distance between the warehouses and the Springfield, Virginia production facility, combined with product need times at the warehouses required to support timely delivery to residences, dictate the priority of shipment as products become available for transport from the production facility. Directional routes are not being considered for the purpose of this project. The term route will be used to describe mileage and estimated time between facilities given the warehouse addresses that have been provided from the WPCD management team. [see **FIGURE 4**]

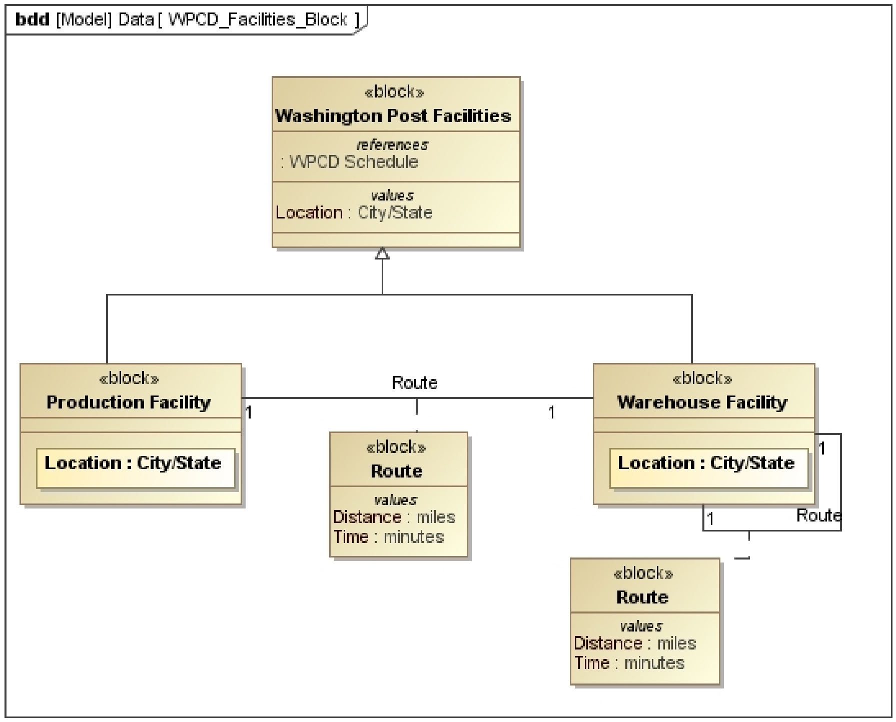


FIGURE 4

The Washington Post newspaper product includes both Sunday and Daily newspaper packages that are delivered to Washington, D.C., Maryland and Virginia residences. Each of these product packages are broken into multiple types. The Daily Package is split into an advance package and a headsheet, better known as the front page. The Sunday Package is also split into a main package and a headsheet, but also includes two advanced packages, ADV1 and ADV2. Headsheets are extremely time sensitive. The Washington Post strives for their headsheets to contain the most late breaking news stories. This requires the headsheet products to be produced as late as possible, but they still need to be produced in time to support timely delivery at each warehouse as needed.

Each newspaper product varies in volume on a daily basis. Variables such as advertisements, leaflet inserts, catalogs, coupons, magazines, and special holiday editions all cause continuous fluctuations in product volume. Product volume for a given day is estimated the night before. This projected product volume is provided to the WPCD management team so that they can use the volume projections along with warehouse demands to build the truck and driver schedule for the upcoming day's route planning. [see **FIGURE 5**]

Daily Paper products are manufactured and delivered daily, throughout the week. Sunday Package products are manufactured and shipped both throughout the week as well as on Saturday night. Detailed information regarding product shipment times can be found in section 1.8 System Behavior: Schedules.

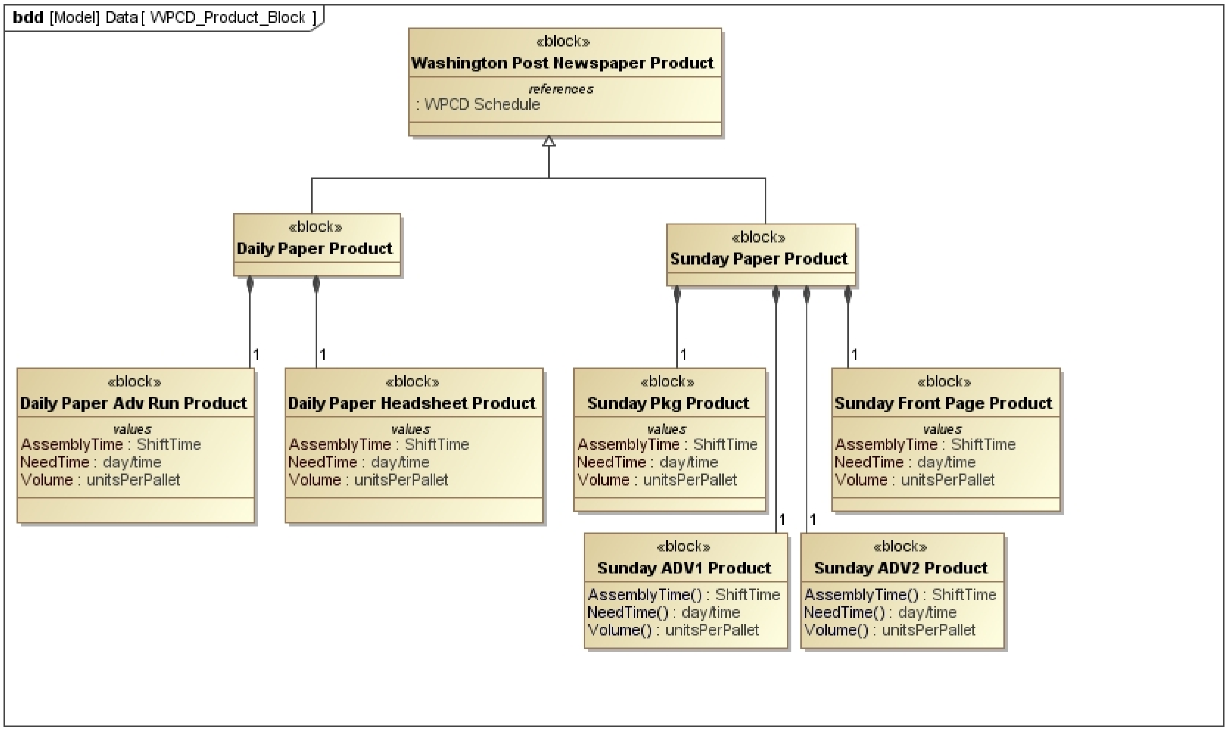


FIGURE 5

The current Washington Post truck fleet consists of a variety of trucks that are used interchangeably as needed to support delivery of all newspaper products produced at the Springfield, Virginia production facility. Fleet makeup consists of trucks of various size and pallet capacity.

At the present time, the fleet includes nine straight trucks which can hold fourteen pallets each, twenty tractors with trailers, four thirty-two foot trailers which can hold eighteen pallets each, one thirty-six foot trailer which can hold twenty pallets each, thirteen forty-eight foot trailers which can hold up to twenty-eight pallets each, and two fifty-three foot trailers which can carry thirty pallets each.

The Washington Post leases all trucks in its fleet from one of two companies, Penske or Robinson Terminal Warehouse. Penske provides straight trucks and tractor trailers, and its sister company Robinson Terminal Warehouse provides additional tractor trailers. Trucks are typically leased on a seven year term, with term end dates varying across the fleet. Truck rental costs include a standard lease rate as well as a charge per mile for usage, which varies between straight trucks and tractor trailers. [see **FIGURE 6**]

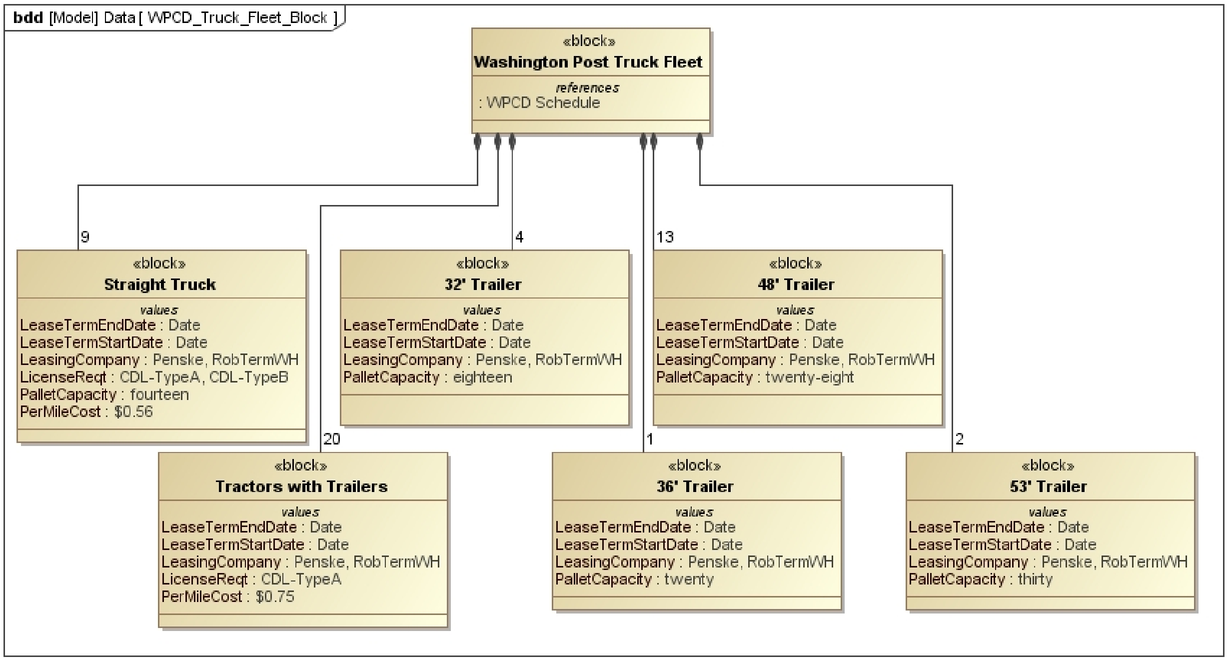


FIGURE 6

The Washington Post's current driver staff is comprised of thirty full-time and thirty part-time drivers. All drivers who are presently employed by the Washington Post hold a Commercial Drivers License (CDL). The Washington Post Circulations Department management team requires that all of their drivers hold a CDL to allow for flexibility in truck and driver assignment and scheduling. Of the drivers on staff, fifty-five have a Class A Commercial Drivers License (CDL) and five have a Class B CDL. Class A CDL drivers can drive any truck in the fleet, and are therefore the most expensive by hourly rate. Class B CDL drivers are limited to only driving straight trucks, and have a less expensive hourly rate. All trucks in the current fleet require drivers to have a Commercial Drivers License. [see **FIGURE 7**]

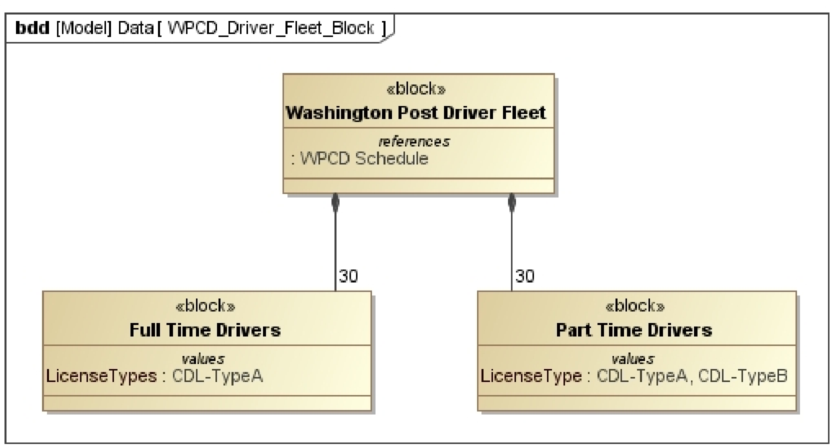


FIGURE 7

Despite a relatively small number of system components at the basic level, the combination of relationships, dependencies and variability among the Washington Post Circulations Department system's subsystems set the foundation for a very complex system. The schedule lies at the core of the WPCD system. Because of its significance, the WPCD management team is focused on optimizing the generation and execution of the WPCD schedule in the hopes of improving overall cost efficiencies in WPCD operations. [see **FIGURE 8**]

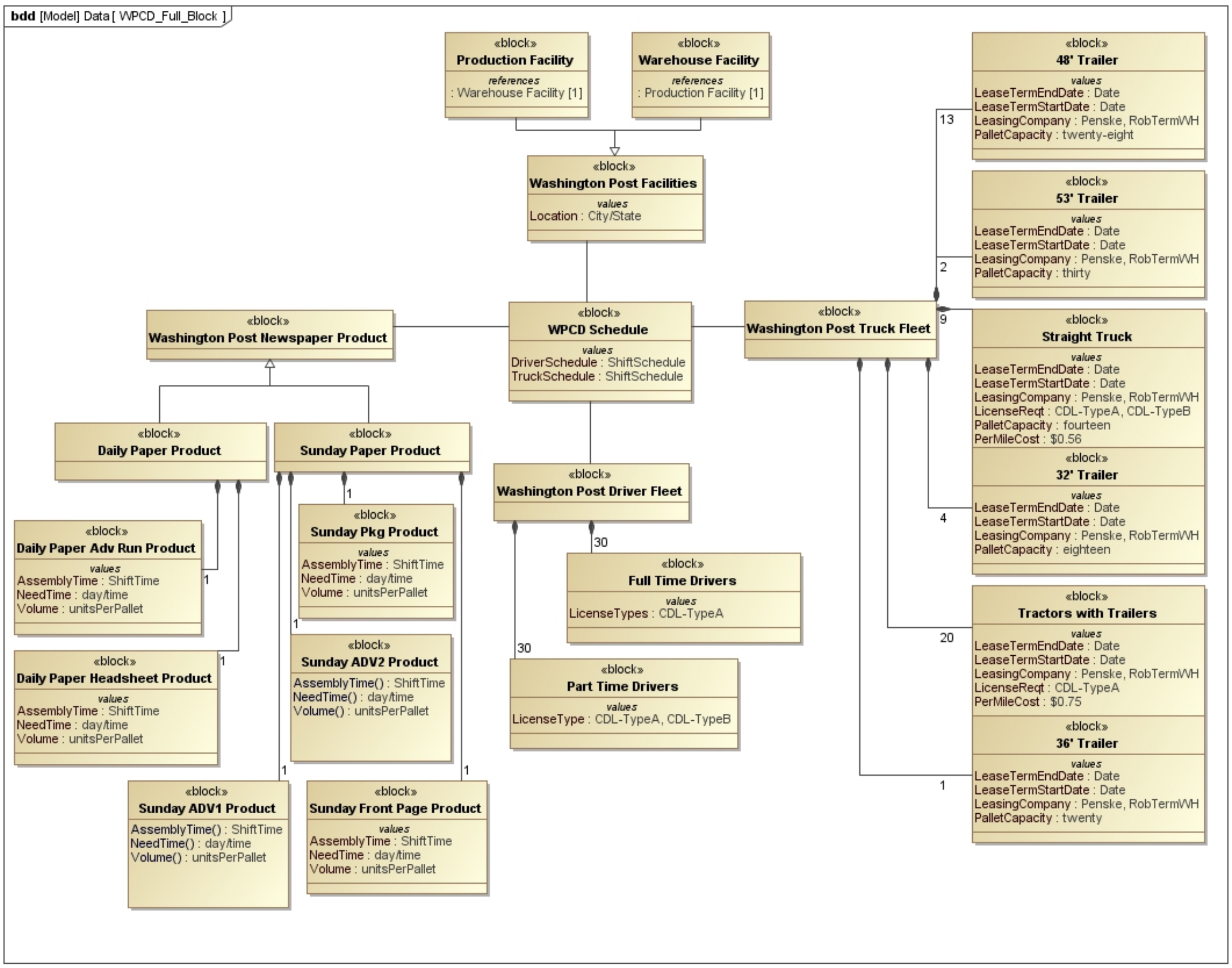


FIGURE 8

5.7 System Behavior: Activity Diagram

Any one activity thread of the Washington Post Circulations Department system is in itself, fairly straightforward. Newspaper product is produced at the Springfield, Virginia production facility and is palletized for shipment. As product pallets become available, the pallets are loaded into a truck and the truck is driven to its destined warehouse. Once at the warehouse, the pallets are unloaded and the truck returns to the production facility. If additional paper product is ready for shipment, the process then repeats. Once all product is delivered for a given week, transportation shifts stop and do not begin until the production facility starts to produce product for the next week. [see **FIGURE 9**]

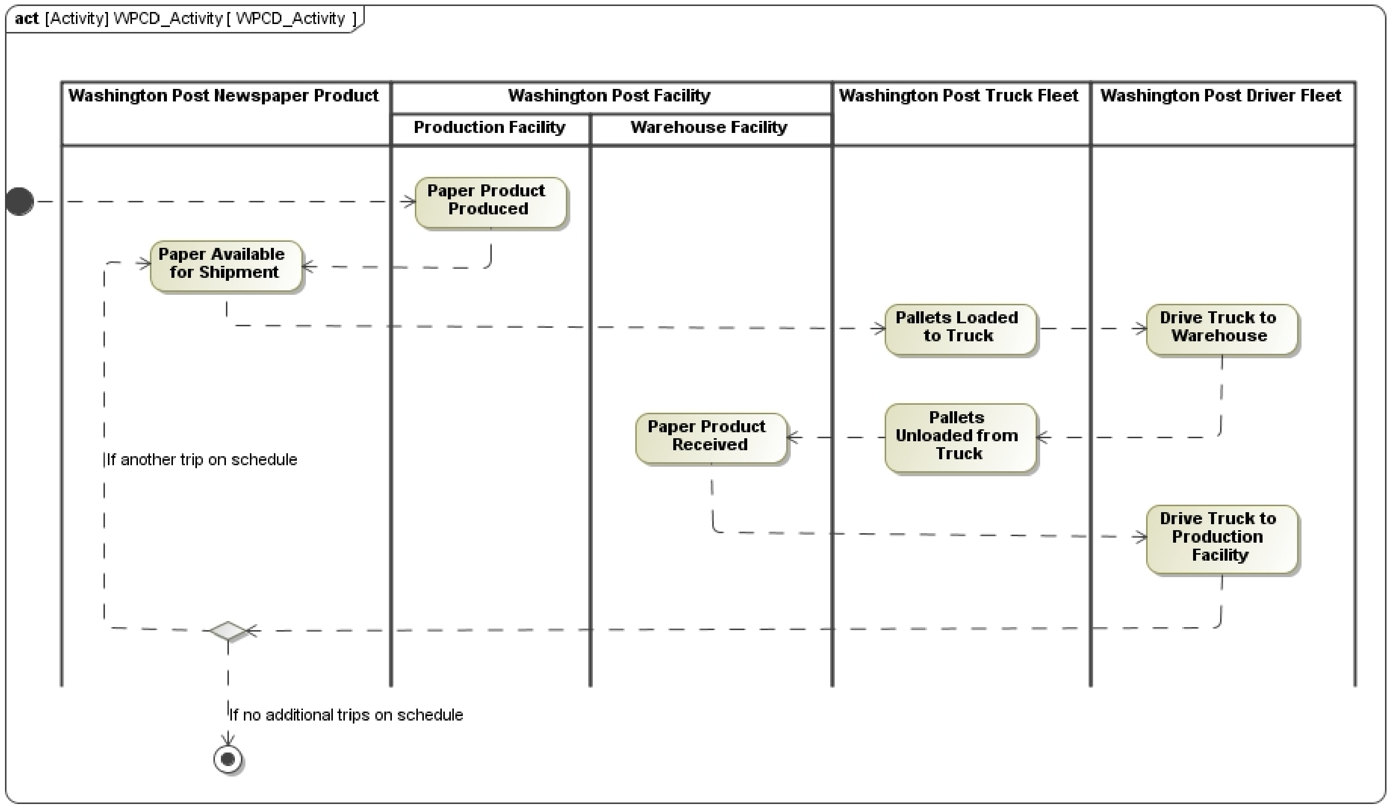


FIGURE 9

What makes the WPCD system processes so complex is the compilation, overlap, pallet number variability and time restrictions based on product type and demand of the single process thread described above. The concurrency of these product threads make for complexities such as one truck containing pallets of multiple product types, with each type potentially having different need times at various warehouses. Warehouse proximity to the Springfield, Virginia production facility also forces first-off-the-line product to be shipped to warehouses that are located the farthest from Springfield, Virginia due to longer routes for those specific warehouses, so trip priorities are an additional complicating factor.

Warehouses with a higher product demand may require larger trucks or more trips on a daily basis to account for a higher number of pallets. On the contrary, warehouses with less product demand may be serviced by one truck loaded with product for two warehouses. In such a case the truck may stop at one warehouse location, drop off part of the product load, and continue on to another warehouse location in relative proximity to deliver the final portion of their load before returning to the production facility. [see **FIGURE 10**]

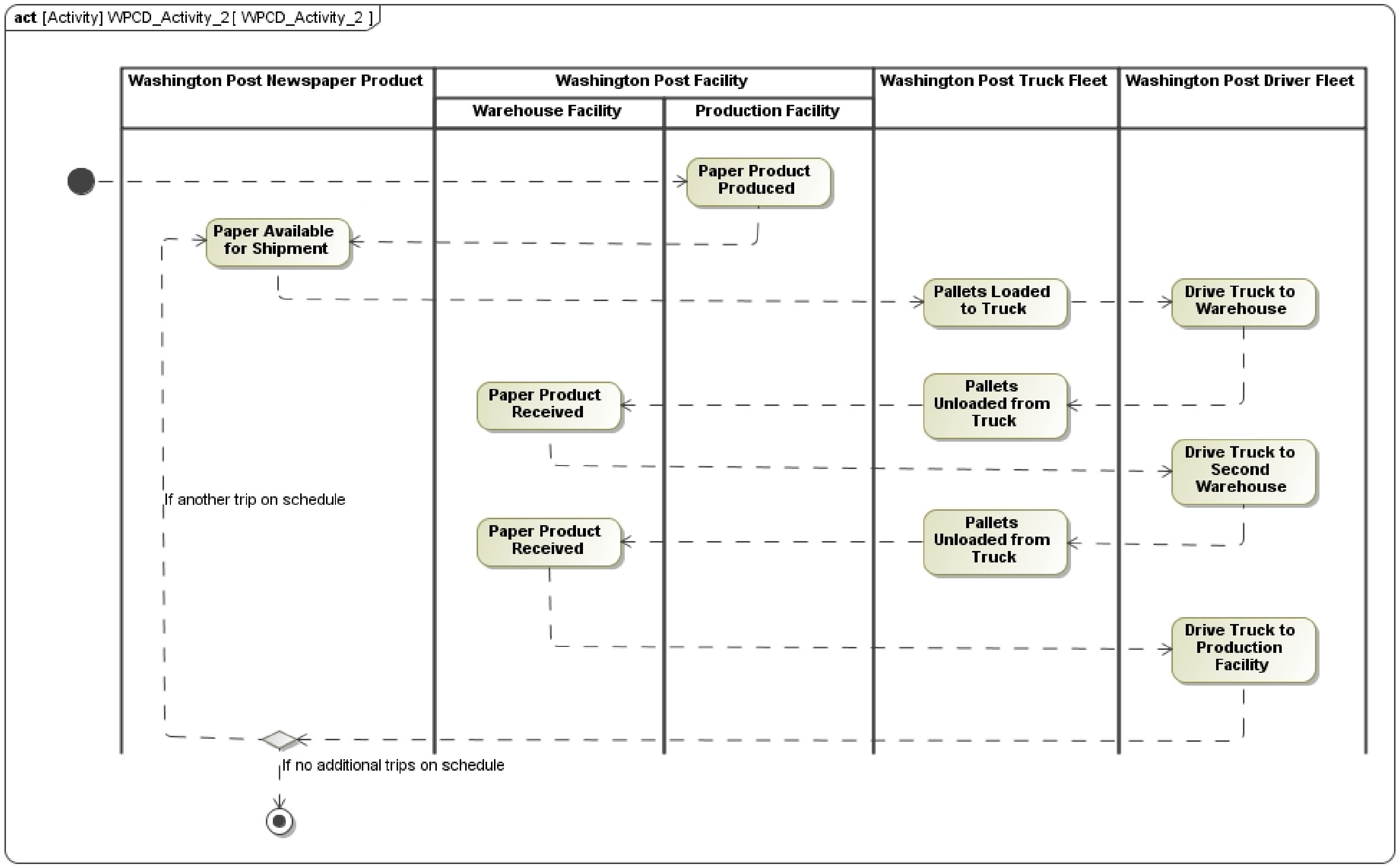


FIGURE 10

The goal of our system model was to be able to capture these process complexities in order to simulate the current workings of the WPCD system. Once the GMU Team was able to sufficiently model the composite processes of the WPCD system, analysis was then performed in order to identify process and cost efficiency gains.

5.8 System Behavior: Schedules

At the highest level, the weekly schedule is derived based on when the various product types are ready to be shipped from the Springfield, Virginia production facility and the need times at each of the multiple warehouses. Schedule windows describing product production times, by type, relative to warehouse need times are described below and in **FIGURE 11**. Product production times and warehouse need times are considered to be a constant in regards to the scope of the WPCD system. The current system's shipment windows, by product type, are described alongside their respective product production windows in **FIGURE 12**. These shipment window times have been considered candidate for variability as needed if the GMU Team's analysis indicates a change in these times may prove to be beneficial to system operations.

Daily Paper products are manufactured and delivered daily, throughout the week. The Daily Paper Advanced Runs are assembled Monday through Friday from 6:00am to 9:30pm for the next day's edition. They are currently shipped Monday through Friday evenings, from 6:00pm to 11:00pm and are required to be at the warehouses by 11:00pm each day. The Daily Paper Headsheets, or front page sections, are assembled Sunday through Friday from 11:00pm to 4:00am to produce the next day's edition. This product type is shipped Sunday through Friday, 11:00pm to 4:00am. Daily Paper Headsheets are required to be at the warehouses by varying times to support on time delivery to residences each morning. The Washington Post strives for Daily Papers to ultimately be delivered to residences by 6:00am each morning.

Sunday Package products are manufactured and shipped both throughout the week as well as on Saturday night. The Sunday Packages are assembled Monday to Thursday, three full shifts per day, and are currently being shipped Monday through Thursday throughout the week. The Sunday Packages are required to arrive at each warehouse by Thursday at 11:00pm. The Sunday Front Page products are assembled Saturday 11:00pm to Sunday 4:00am. They are shipped Saturday night 11:00pm to 4:00am with the product required to be at the warehouse at varying times. The Sunday Paper ADV1 products are assembled Friday mornings and are shipped Friday afternoon and evening prior to the Daily Headsheet product shipment. The Sunday Paper ADV2 products are assembled Saturday mornings and are shipped Saturday afternoon and evenings prior to the Sunday Headsheet product shipment. The Washington Post strives for Sunday Papers to ultimately be delivered to residences by 6:00am on Sunday mornings.

Lower level scheduling fluctuates on a weekly basis, due to product volume inconsistency. At the lower level, the weekly schedule includes detailed truck and driver trip schedules. Because of product volume variability, schedule details such as truck types and the number of runs change on a daily basis. As a result, driver detailed schedules change as well to accommodate the truck type and truck run schedules. Due to the inconsistency in detailed weekly truck and driver schedules, the route level schedule is not described or depicted in this document, but instead has been be simulated in our system model.

5.8.1 Schedule: Production Runs and Need Times

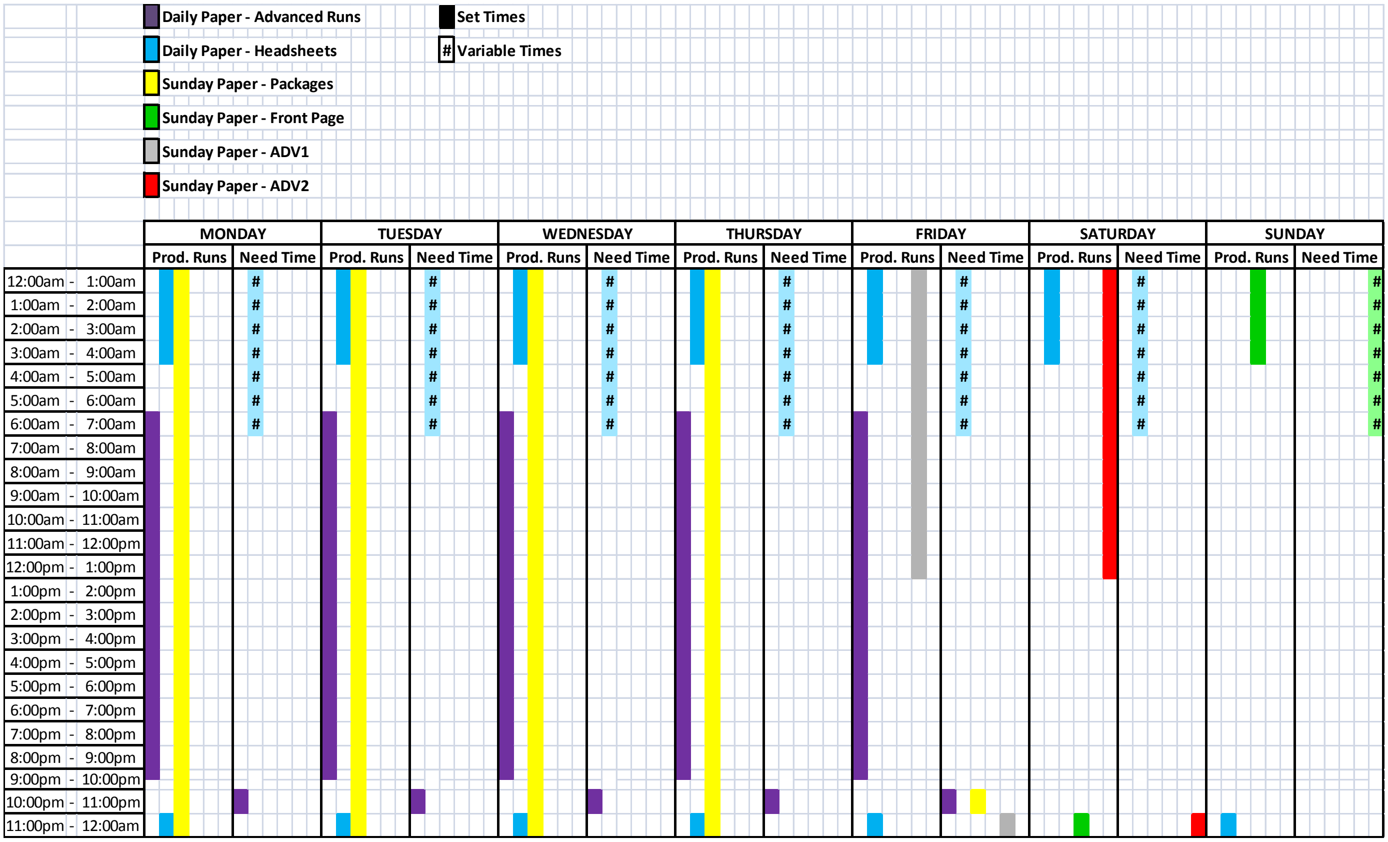


FIGURE 11

5.8.2 Schedule: Production Runs and Current Transport Times

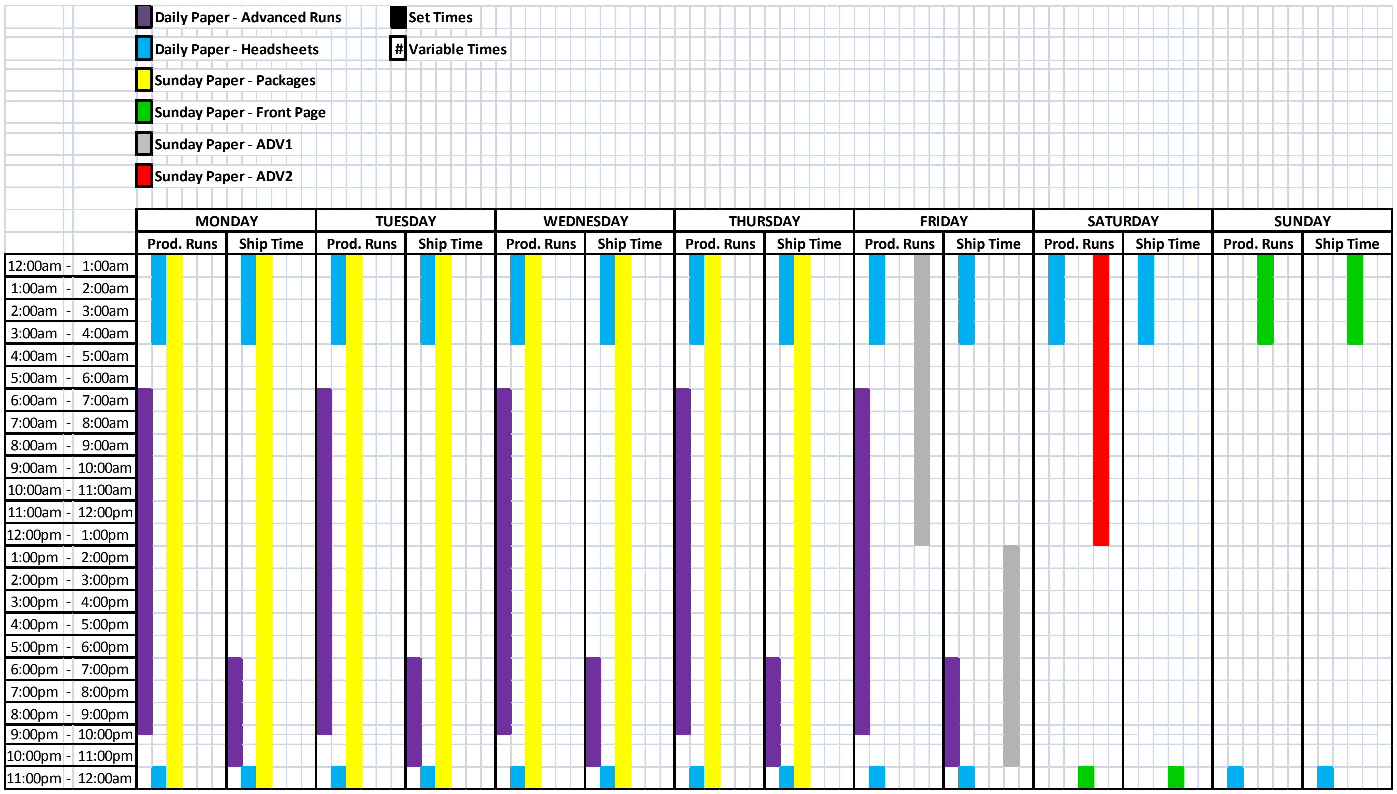


FIGURE 12

As a result of documenting the WPCD high-level schedule, it is observed that the Monday through Thursday schedule is common at a shift level due to consistency in the production and need times of the Daily Paper Product. The weekend schedule (Friday through Sunday) fluctuates due to changing product types and product demands associated with weekend deliveries as seen below in **FIGURE 13** and **FIGURE 14**.

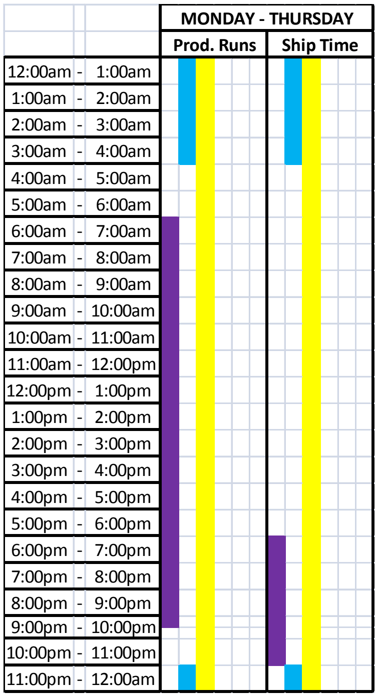


FIGURE 13

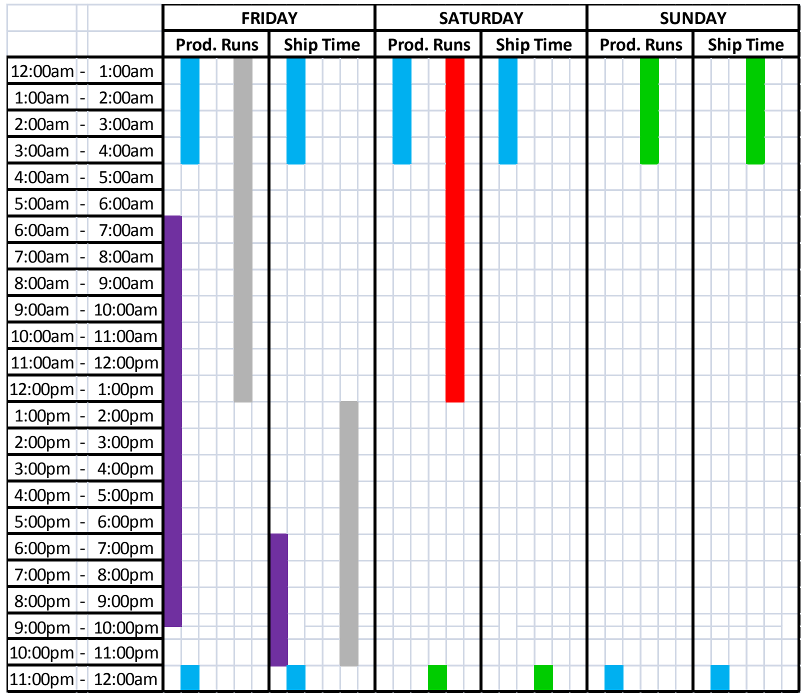


FIGURE 14

6 Truck Scheduling Model

6.1 Model Selection and Construction

A literature review was done to identify solution methods to similar problems. Although there are probably other ways to model this problem, our research focused on two methodologies. The first is based on so called rich vehicle routing problems (VRP). Problems in this class tend to have multiple side constraints that complicate the mathematical formulation. For example, in this case, there are time windows for product production and delivery, a non-homogeneous truck fleet, and multiple product types. The most difficult side constraint to model correctly is the fact that a single truck can make multiple tours in a single route. Although we did implement this methodology for a reduced network and without time windows (see Appendix E for formulation) our experiments did not support the feasibility of scaling up this methodology to encompass all complexities of the problem. The reader is directed to Appendix B [1]-[3] and references therein to see how others have implemented this strategy.

The methodology that we have spent the bulk of our time researching and implementing is based on the concept of a **Time-Space Network**. Time-space networks have been used to dynamically route vehicles [4] as well as dynamically schedule airline crews. The key insight for the time-space networks is that nodes in the network correspond not only to physical locations, but also to specific times as well. So a node in the network might be the production plant at 8:00 am, and another might be the production plant at 8:30 am. While the VRP formulations struggle with dealing with the time index for decision variables, in time-space networks these difficulties are avoided simply by the structure of the network. Arcs connecting nodes in the network represent feasible routes to send products. The problem then becomes a sort of network flow problem. We want to flow products from the source (depot nodes at their time of production) to their destinations (distribution centers) at minimal costs. Product flow over feasible arcs is capacitated by the selection of which truck type travels across the arc. While the mathematical formulation of this model is relatively straightforward in that there are only capacity constraints and flow balance constraints, significant preprocessing must be done to ensure that the structure of the network accurately reflects feasible transportation routes.

The following is the mathematical formulation for one implementation of a time-space network for The Washington Post dynamic routing problem.

$N = \{0 \dots n\}$: The set of nodes in the time-space network.

$(i, j) \in A$: The set of feasible arcs in the time-space network.

$k \in K$: The set of truck types. $|K| = 5$. There is one straight truck type and four tractor trailer types.

C_k: The capacity (pallets) of truck type k.

D_{ij}: The distance in miles from node i to node j.

V_k: The cost per mile of using truck type k.

$x_{ij}^k \in \{0, 1\}$: This binary variable corresponds to whether or not a truck of type k is traveling from node i to node j.

$\bar{x}_{ij}^k \in \mathbb{Z}^+$: This variable corresponds to the number of trucks of type k which are kept at the production plant in successive time intervals. Note that these variables only exist for arcs between the production plant at different times. It is also important to note that they are integer and not binary. Otherwise we could at most keep 1 of each type of truck at the production plant from time period to time period.

$p \in P$: The set of products (headsheets, inserts, sunday advance, etc.) to be delivered to the distribution centers.

$y_{ij}^p \in \mathbb{Z}^+$: The integer number of product $p \in P$ that is carried between nodes $i, j \in N$.

$\bar{y}_{ij}^p \in \mathbb{Z}^+$: The integer number of product $p \in P$ that is carried between the same distribution center at different times. Note that these variables only exist for arcs between the nodes corresponding the same distribution center at different times.

b_l and b_l': These correspond to the flow-balance constraints. If b_l or b_l' equals 0 then the node is a transhipment node. If they are positive or negative, then the node is either a source or a sink.

$$\min \sum_{(i,j)\in A,k} D_{i,j} V^k x^k_{i,j}$$

$$\sum_p y^p_{i,j} \leq C^k x^k_{i,j} \qquad \forall (i,j) \in Y \qquad (1)$$

$$\sum_{i,p} (y^p_{i,l} + \bar{y}^p_{i,l}) - \sum_{j,p} (y^p_{l,j} + \bar{y}^p_{l,j}) = b_l \qquad \forall l \in N \qquad (2)$$

$$\sum_{i,k} (x^k_{i,l} + \bar{x}^k_{i,l}) - \sum_{j,k} (x^k_{l,j} + \bar{x}^k_{l,j}) = b'_l \qquad \forall l \in N \qquad (3)$$

$$y^p_{i,j},\ \bar{y}^p_{i,j},\ \bar{x}^k_{i,j} \in \mathbb{Z}^+,\ x^k_{i,j} \in \{0,1\} \qquad (4)$$

FIGURE 15: TIME-SPACE NETWORK FORMULATION

(1) is the set of capacity constraints. (2) is the set of flow balance constraints for the products. (3) is the set of flow balance constraints for the trucks.

In the formulation above, the model assigns individual pallets to trucks. We call this formulation **Single Unit**. If we wanted to force the model to only consider entire orders, it is a relatively straightforward operation. The variables corresponding to product flow (y's) change to integer and we need to multiply the left hand side of (1) by the pallets in each order. We call this formulation **Batch.** The hypothesis was that by reducing the product flow variables from integer to binary, we would reduce the complexity of the problem. Similarly, we tried another formulation called **0-**1 where we made a truck type for every truck in the fleet all with availability 1. This reduces the entire model to containing all binary variables. Our hypothesis again was that this would reduce the complexity of the problem. This 0-1 formulation does make all of the decision variables binary, but increases the number of variables dramatically (we no longer have 5 truck types, but 29 truck types each with availability 1).

After testing traditional VRP formulations that weren't viable, the three Time-Space Network formulations above were implemented. Initial tests seemed to provide confidence that the problem could be solved in a short enough amount of time in order to support the WPCD's need for daily solutions. The model uses Excel as a front end. Excel is a product the WPCD has available to it, which reduces the implementation cost. Excel also offers an easy solution to providing a user interface that the WPCD is familiar with. Due to the size and complexity of the model, Excel is not capable of solving the problem. CPLEX was selected as the solver engine due to its availability and power. This will increase the cost for the WPCD to implement the model, but by offering a business case for implementation, the cost savings will more than pay for the cost of the CPLEX license.

The formulation of the truck routing model allows us to model the movements of products as they flow through the network with constrained availability of trucks while reducing the cost. The model accepts daily product volume and warehouse demands. The model combines shipments into one route that serves multiple distribution centers where it is feasible and cost effective to do so.

6.2 User Interface

The Washington Post Team expects that readership levels will decline in the coming years. This will drive changes in the levels of product being delivered. Due to the changing nature of the distribution operation an optimal solution will be short-lived, and the problem will have to be re-evaluated. Also, the nature of the volume of truck space needed in any given week can vary greatly based on the number of inserts. It's crucial that the model provides a User-Friendly experience that allows the Washington Post team to operate it unassisted in the future with updated parameters.

The front-end Excel spreadsheet offers an easy interface to update the list of distribution centers as they change. The user simply deletes the distribution center name and the model will reflect the new operation. Since the number of pallets shipped to each distribution center will change on a daily basis, this information is easily updated and the model will recalculate a solution.

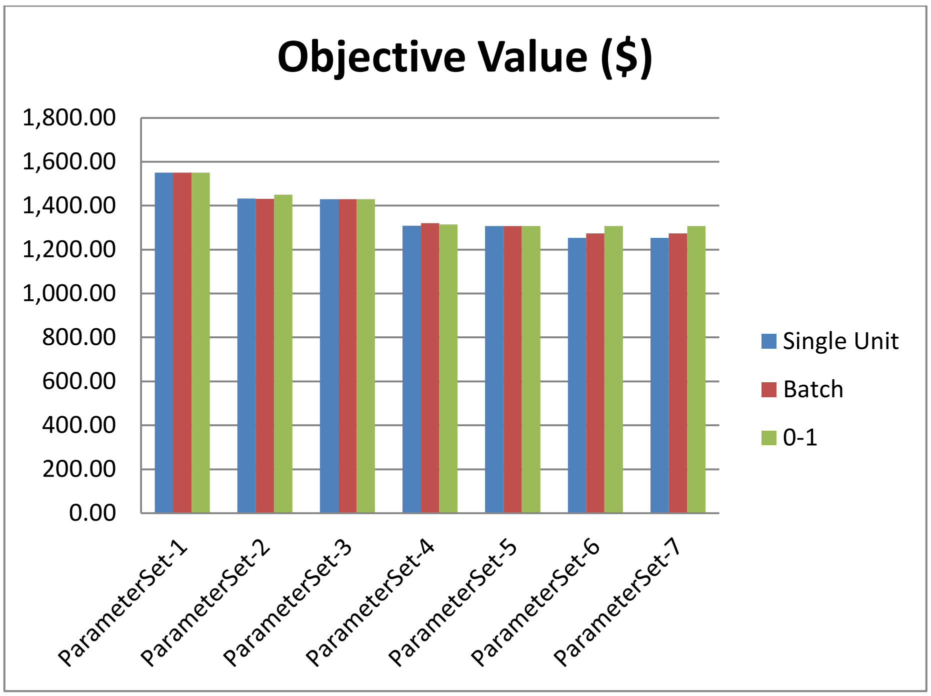
The user can also adjust four main parameters to control the size of the problem and which solutions they are looking for. The first is the **Time Interval** parameter. This controls the granularity of the solution. A time interval of 30 minutes divides the workday (also user defined) into 30-minute steps. If the value of the time interval is small, then the associated network will be large and thus the problem will be difficult to solve. Conversely, if the time interval is too big, then the solutions do not provide enough information to be practically useful. In our tests, we have empirically determined 30 minutes to be a good default value for the time interval parameter.

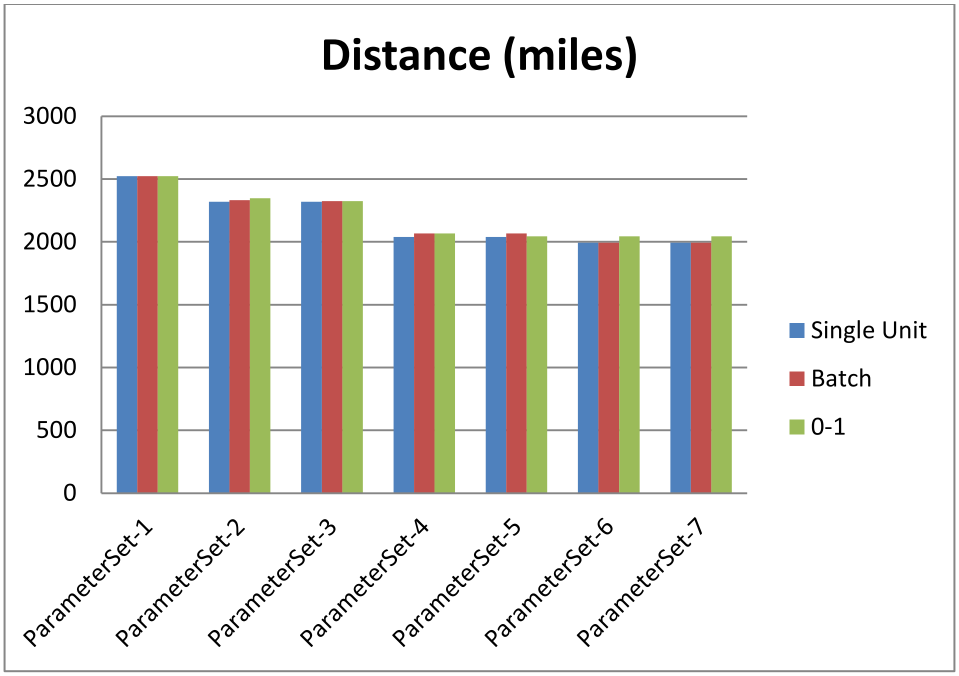
The user can also adjust the **Loading Time** parameter. This parameter is pretty much self-explanatory. The loading time is added to the travel times when considering feasible arcs in the network. The user suggested that the loading time be a function of the number of pallets that are carried over an arc in the network, however this makes the problem nonlinear since we don't know a-priori how many pallets are going to be carried over a specific arc.

The third user-defined parameter is the **Max Hold**. The model cuts costs by "bundling" orders onto a single truck that is assigned a multi-distribution center tour. It is cheaper to send one truck to two places than it is to send two trucks to one place each. The max hold parameter controls this bundling by defining the maximum allowable time (in minutes rounded to the nearest time interval) that an order can stay at the production plant. If the max hold is large, then there is the possibility for more bundling as more orders are produced. If max hold is small, then the model will produce solutions where most orders are put on separate trucks. We find empirically that a max hold time of 120 minutes produces good solutions.

The last parameter, **Time Bound**, is a little trickier to explain. The time bound, like the max hold, affects how much bundling can occur. The time bound is what determines which arcs in the network are feasible. For example, when time bound is zero, the only feasible arcs in the network are from the production plant to each distribution center (and back). As time bound is increased, if the travel time between two locations (plus the loading time) is less than the time bound, then that arc is included in the network. We see diminishing returns with either extreme of the time bound parameter. If the time bound is too small, then only plant-distribution center-plant routes are considered and therefore no bundling occurs. On the other hand, if the time bound is very large, say two hours, then we will be considering arcs that would never be optimal. For example, it will never be optimal to drive from the production plant to the distribution center in Hollywood, then up to Annapolis, and then back to the depot. Having a large time bound greatly increases the number of arcs (equivalently variables) in the network and therefore increases the difficulty of the routing problem. We find empirically that a time bound of 60 minutes produces good solutions.

The following tables summarize our experiments tuning these parameters on one day of demand data.





	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
ParameterSet-1	0	30	60
ParameterSet-2	30	30	60
ParameterSet-3	45	30	60
ParameterSet-4	60	30	60
ParameterSet-5	90	30	60
ParameterSet-6	60	30	120
ParameterSet-7	60	30	180

Figure 16: Parameter Tuning for all three models (Single Unit, Batch, 0-1)

Our testing of the three different time-space network models (Single Unit, Batch, and 0-1), the Single Unit formulation was marginally better than the other two. For the remainder of our tests we used this formulation.

By providing the Washington Post team with a model that is easy to use and update, the WPCD can continue to evaluate solutions to the truck routing problem even in a changing environment.

6.3 Scalability

The Truck Routing model allows the user to scale the model as constraints change. The location of new distribution facilities can be added by adding the facility name and making additional entries into the distance and time tables. If a distribution center is closed it should be removed from the distribution center list and the time and distance matrix. These updates are made in excel by the user at runtime. The expectation is that the amount of product can vary greatly day to day. The user can change the amount of product and recalculate the solution in a few minutes using the model. This makes it a viable solution for daily use. The fleet parameters can be updated to reflect trucks that are out of service or additional trucks that are leased on a short-term basis. For additional information on model usage, see **APPENDIX F: WPCD SCHEDULING TOOL USER MANUAL.** Being able to scale the fleet allows any future changes in the fleet makeup to be incorporated by the user into the model.

6.4 Model Parameters

The Operational Scenario will help define the model's flow.

1. **Current Fleet Parameters**
    - **a.** Straight Trucks (9) which can hold 14 pallets each
    - **b.** Tractors with trailers (20)
        - **i.** 32' trailers (4) which can hold 18 pallets each
        - **ii.** 36' trailers (1) which can hold 20 pallets each
        - **iii.** 48' trailers (13) which can hold up to 28 pallets each
        - **iv.** 53' trailers (2) can carry 30 pallets each
2. **Current Cost Parameters**
    - **a.** Leasing Costs for each type of truck
    - **b.** Cost/mile for each type of truck
        - **i.** $0.56 – Straight Trucks
        - **ii.** $0.75 – Tractor Trailers
3. **Route Parameters**
    - **a.** Miles for each valid route between 28 facilities
    - **b.** Speed/time (minutes) for each valid route between 28 facilities
4. **Network Parameters**
    - **a.** Time Interval
    - **b.** Loading Time
    - **c.** Max Hold
    - **d.** Time Bound

6.5 Input Data

The WPCD supplied 2 months of production and delivery data in the form of a database. The database contained an entry for each pallet that was produced. **FIGURE 17** is an excerpt of the database. The Issue Date field corresponds to the date of the newspaper. The product type identifies it as a Full Press Run, an advertisement, or part of the Sunday product. The production time is the scan time when the pallet is wrapped and ready for shipment. The destination is the distribution center that the pallet needs to be shipped to.

Issue Date	Product Type	Production Time	Destination
8/14/2011	Full Press Run	08/13/2011 12:05:01	DERWOOD
8/14/2011	Full Press Run	08/13/2011 20:23:55	HOLLYWOOD
8/14/2011	Dist of Columbia RE Resale Zon	08/13/2011 19:03:36	SILVER SPRING

FIGURE 17

The entire database is contained in appendix C. In order to get the data into a useable format a sorting program was developed in Excel to add the pallets into a total number of pallets of the same type. It combined 3 unique entries of Full Press destined for Derwood into one lot of three pallets with the latest production time destined for Derwood. By combining the pallets into lots, it eases the data entry and solving of the model. **FIGURE 18** contains the data for one day 8/15/2011. Additional days of model input data that were used in the truck routing model validation are attached in Appendix C.

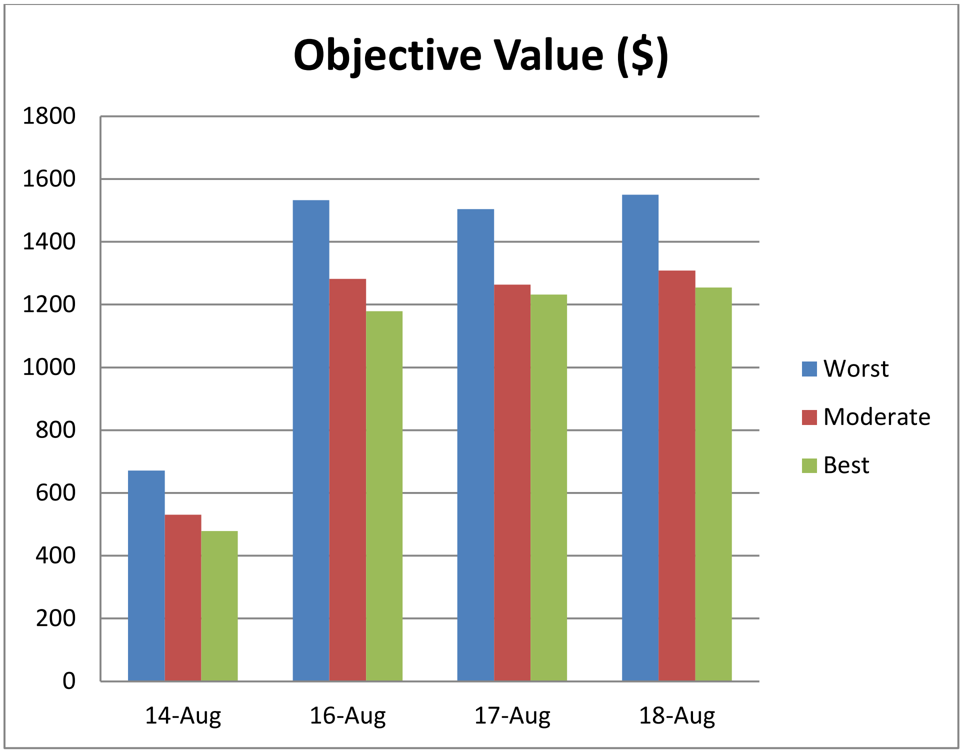
Destination	Product ID	8/15/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Full Press Run	5	8/15/2011 1:17	8/15/2011 4:00
ANNAPOLIS	Full Press Run	6	8/14/2011 22:40	8/15/2011 4:00
ARLINGTON	Full Press Run	4	8/14/2011 22:55	8/15/2011 4:00
ANNAPOLIS JUNCTION	Full Press Run	3	8/14/2011 23:00	8/15/2011 4:00
BOWIE	Full Press Run	6	8/14/2011 23:40	8/15/2011 4:00
BURKE	Full Press Run	8	8/15/2011 0:51	8/15/2011 4:00
CHANTILLY	Full Press Run	8	8/15/2011 0:00	8/15/2011 4:00
COLUMBIA	Full Press Run	9	8/15/2011 0:21	8/15/2011 4:00
DERWOOD	Full Press Run	13	8/15/2011 0:46	8/15/2011 4:00
DUNKIRK	Full Press Run	0		
FREDERICK	Full Press Run	4	8/14/2011 23:19	8/15/2011 4:00
GERMANTOWN	Full Press Run	6	8/14/2011 23:00	8/15/2011 4:00
HOLLYWOOD	Full Press Run	1	8/14/2011 22:55	8/15/2011 4:00
HYATTSVILLE	Full Press Run	8	8/14/2011 22:25	8/15/2011 4:00
LEESBURG	Full Press Run	0		
MANASSAS	Full Press Run	4	8/14/2011 22:25	8/15/2011 4:00
OXON HILL	Full Press Run	3	8/15/2011 0:51	8/15/2011 4:00
PURCELLVILLE	Full Press Run	0		
ROCKVILLE	Full Press Run	10	8/15/2011 0:51	8/15/2011 4:00
SEAT PLEASANT	Full Press Run	3	8/14/2011 22:55	8/15/2011 4:00
SOUTH DAKOTA	Full Press Run	9	8/14/2011 23:42	8/15/2011 4:00
SPRINGFIELD	Full Press Run	5	8/15/2011 1:46	8/15/2011 4:00
STERLING	Full Press Run	7	8/14/2011 22:25	8/15/2011 4:00
VIENNA	Full Press Run	9	8/15/2011 1:54	8/15/2011 4:00
WALDORF	Full Press Run	4	8/14/2011 22:55	8/15/2011 4:00
WARRENTON	Full Press Run	0		
WHITE OAK	Full Press Run	4	8/15/2011 0:51	8/15/2011 4:00
WOODBRIDGE	Full Press Run	3	8/14/2011 23:06	8/15/2011 4:00
ALEXANDRIA	Ads	0		
ANNAPOLIS	Ads	0		
ARLINGTON	Ads	0		
ANNAPOLIS JUNCTION	Ads	0		
BOWIE	Ads	0		
BURKE	Ads	0		
CHANTILLY	Ads	0		
COLUMBIA	Ads	0		
DERWOOD	Ads	0		
DUNKIRK	Ads	0		
FREDERICK	Ads	0		
GERMANTOWN	Ads	0		
HOLLYWOOD	Ads	0		
HYATTSVILLE	Ads	0		
LEESBURG	Ads	0		
MANASSAS	Ads	0		
OXON HILL	Ads	0		
PURCELLVILLE	Ads	0		
ROCKVILLE	Ads	0		
SEAT PLEASANT	Ads	0		
SOUTH DAKOTA	Ads	0		

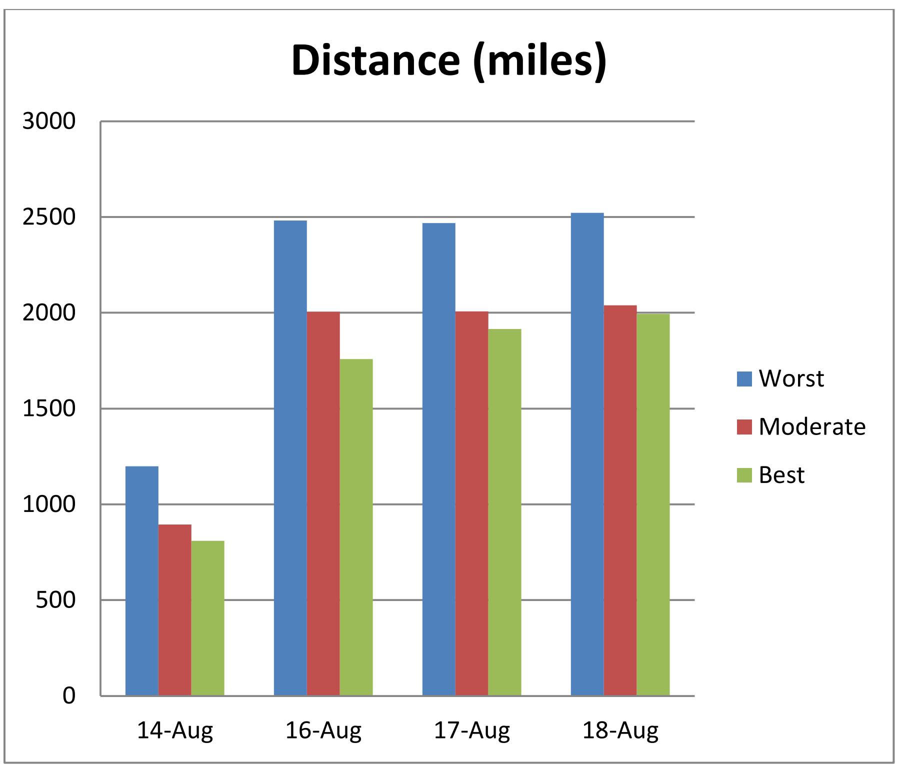
SPRINGFIELD	Ads	0		
STERLING	Ads	0		
VIENNA	Ads	0		
WALDORF	Ads	0		
WARRENTON	Ads	0		
WHITE OAK	Ads	0		
WOODBRIDGE	Ads	0		
ALEXANDRIA	Sunday	15	8/15/2011 20:54	8/21/2011 4:00
ANNAPOLIS	Sunday	12	8/15/2011 21:33	8/21/2011 4:00
ARLINGTON	Sunday	14	8/15/2011 22:11	8/21/2011 4:00
ANNAPOLIS JUNCTION	Sunday	6	8/15/2011 21:48	8/21/2011 4:00
BOWIE	Sunday	8	8/15/2011 20:07	8/21/2011 4:00
BURKE	Sunday	17	8/15/2011 20:47	8/21/2011 4:00
CHANTILLY	Sunday	16	8/15/2011 21:27	8/21/2011 4:00
COLUMBIA	Sunday	10	8/15/2011 20:46	8/21/2011 4:00
DERWOOD	Sunday	18	8/15/2011 21:13	8/21/2011 4:00
DUNKIRK	Sunday	0		
FREDERICK	Sunday	0		
GERMANTOWN	Sunday	17	8/15/2011 22:30	8/21/2011 4:00
HOLLYWOOD	Sunday	2	8/15/2011 22:10	8/21/2011 4:00
HYATTSVILLE	Sunday	24	8/15/2011 21:44	8/21/2011 4:00
LEESBURG	Sunday	2	8/15/2011 21:37	8/21/2011 4:00
MANASSAS	Sunday	13	8/15/2011 21:15	8/21/2011 4:00
OXON HILL	Sunday	11	8/15/2011 20:10	8/21/2011 4:00
PURCELLVILLE	Sunday	6	8/16/2011 0:04	8/21/2011 4:00
ROCKVILLE	Sunday	17	8/15/2011 20:28	8/21/2011 4:00
SEAT PLEASANT	Sunday	9	8/15/2011 20:40	8/21/2011 4:00
SOUTH DAKOTA	Sunday	28	8/15/2011 20:41	8/21/2011 4:00
SPRINGFIELD	Sunday	14	8/16/2011 22:21	8/21/2011 4:00
STERLING	Sunday	17	8/15/2011 22:30	8/21/2011 4:00
VIENNA	Sunday	21	8/15/2011 21:39	8/21/2011 4:00
WALDORF	Sunday	7	8/15/2011 19:58	8/21/2011 4:00
WARRENTON	Sunday	0		
WHITE OAK	Sunday	14	8/15/2011 21:16	8/21/2011 4:00
WOODBRIDGE	Sunday	11	8/15/2011 22:16	8/21/2011 4:00

FIGURE 18

6.6 Results

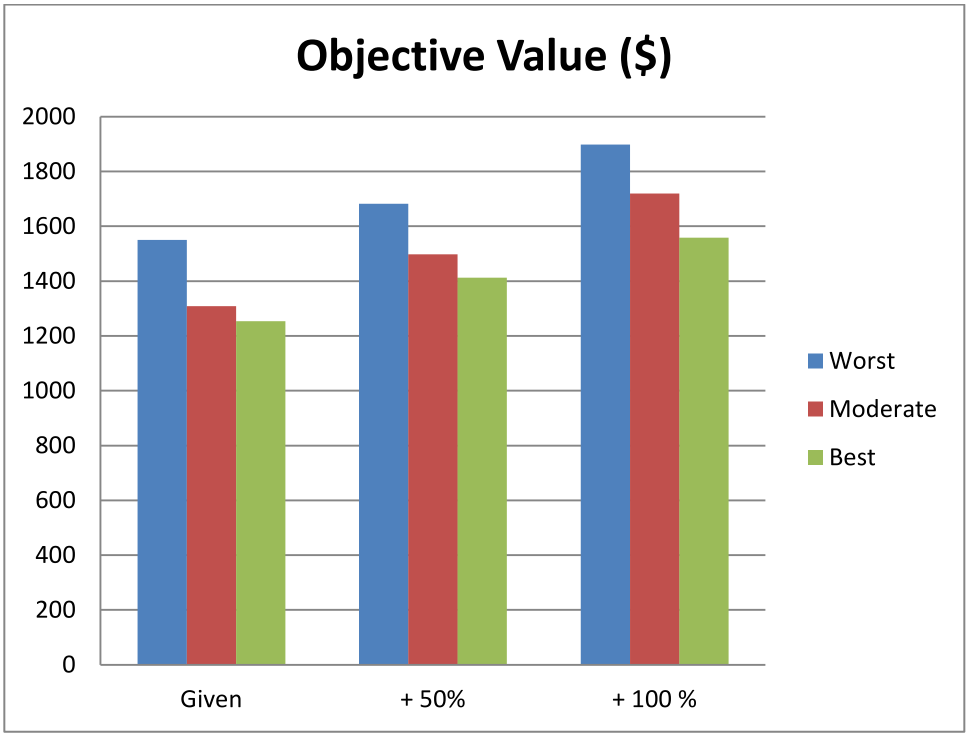
We took demand for four days and ran it through the Single Unit model. We were able to find solutions in all test cases that reduced driving costs between $200 and $300 per day and 400 to 500+ total driving miles per day. The results are summarized below in **FIGURE 19.** We next looked at a single day and increased demand by 50% and then 100% as a stress test for the system. The results are summarized below in **FIGURE 20.**

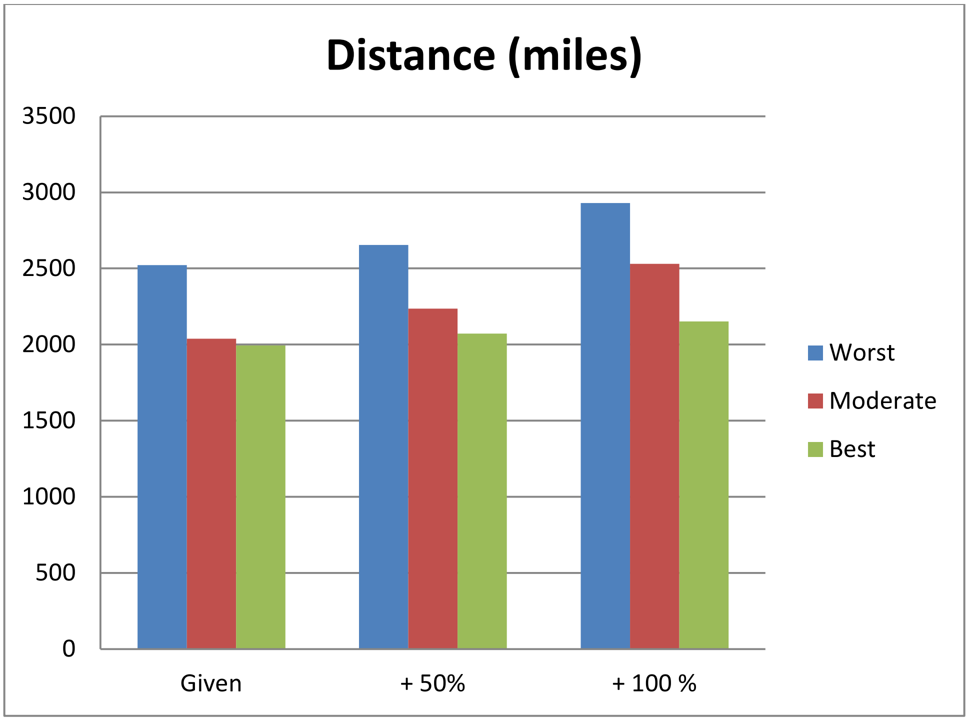

Objective Value ($)
1800
1600
1400
1200
1000
800
600
400
200
0
14-Aug
16-Aug
17-Aug
18-Aug
Worst
Moderate
Best


Distance (miles)
3000
2500
2000
1500
1000
500
0
14-Aug
16-Aug
17-Aug
18-Aug
Worst
Moderate
Best

	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
Worst	0	30	60
Moderate	60	30	60
Best	60	30	120

FIGURE 19: RESULTS OF 4-DAY COMPARISON USING SINGLE UNIT MODEL

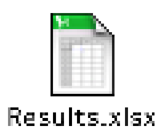




	Time Bound (Min.)	Time Interval (Min.)	Max Hold (Min.)
Worst	0	30	60
Moderate	60	30	60
Best	60	30	120

Figure 20: Results of 1-Day Comparison with increased demand using Single Unit Model

Full results over all test cases are included in the attached spreadsheet.



A partial solution file output by CPLEX for a test run of the Batch model is included in Appendix F. The x variables correspond to truck routing and the y variables correspond to product routing on those trucks.

7 Fleet Mix Model

7.1 Model Selection and Construction

The fleet mix model uses the truck routing schedule as an engine. A linear regression of the data provided by the WPCD was performed to project the product demand in the future. The projected number of pallets is used as an input to the truck routing model. Additionally, the number of trucks available in the model is left unconstrained. The routing solution will use the optimal number of trucks for the projected demand. Using this approach after the implementation of the routing model will allow the WPCD to assess their leasing needs as truck leases expire and need to be renegotiated. They can also use this approach to assess their needs for peak demands like the increased volume of advertisements during the holiday season to evaluate short-term leases. This solution method was selected as an efficient way to solve the truck routing and fleet mix problems and reducing the number of tools to complete the tasks.

7.2 User Interface

The user interface described in the truck routing model section is used again for the fleet mix model, eliminating the need for the WPCD to learn how to use an additional interface. The utilization of the same parameters in a different way allows us to solve both problems.

7.3 Scalability

The WPCD only provided two months of data, so any trend from the linear regression may only reflect seasonally changes. The WP may have better ways of predicting the amount of product they'll need to ship in the future based on sales projections or other methods. The linear regression offers the WPCD an alternative if better projections are not available. More data over a longer time period should be used to calculate the linear regressions in order to see any annual trends in the data. Generally, we would expect the number of pallets to be decreasing because of lower demand. Two cases might drive increases in the future pallet projections. If the WP closes a distribution center, the operations are consolidated with nearby distribution centers which would see increased volumes. Increased advertisement bulk to offset the decline in readership might cause the number of pallets to grow even if the number of newspapers decreases. All of these changes can be accounted for in the pallet projections and the model calculations.

7.4 Model Parameters

1. **Unconstrained Fleet Parameters**
    - **a.** Straight Trucks (?) which can hold 14 pallets each
    - **b.** Tractors with trailers (?)
        - **i.** 32' trailers (?) which can hold 18 pallets each
        - **ii.** 36' trailers (?) which can hold 20 pallets each
        - **iii.** 48' trailers (?) which can hold up to 28 pallets each
        - **iv.** 53' trailers (?) can carry 30 pallets each

2. **Current Cost Parameters**
    - **a.** Leasing Costs for each type of truck
    - **b.** Cost/mile for each type of truck
        - **i.** \$0.56 – Straight Trucks
        - **ii.** \$0.75 – Tractor Trailers

3. **Pallet Projections**

a. Linear Regression (number of pallets per distribution center)
b. Worst Case Load (number of pallets per distribution center)

4. **Route Parameters**
   a. Miles for each valid route between 28 facilities
   b. Speed/time (minutes) for each valid route between 28 facilities

7.5 Input Data

The Linear Regression was performed on the pallet data for each distribution center destination. The trend based on the data provided by the WPCD is generally showing an increased demand at the distribution center. The raw data was collected during August, September and October of 2011. Increased advertising bulk is expected during the period leading up to Black Friday and the holiday shopping season in addition to the Washington Post's normal advertisements. So while the data makes sense over a short time horizon, it is not a good long-term projection of what the Washington Post's product load will look like in the future. In order to perform an assessment of the fleet mix more data across the entire year or longer would be needed to assess a trend and use it to project into the future more accurately. **FIGURE 21** Below is an example of the linear regression analysis for the Alexandria distribution center. In this case 11 pallets is the projected future demand per day at the Alexandria distribution center. Additional Graphs and the summary data used for the model are provided in Appendix D.

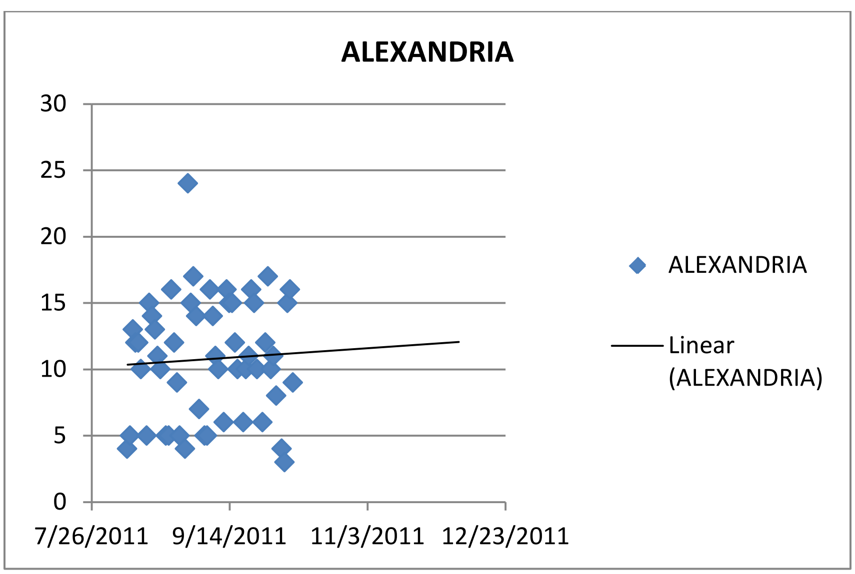


FIGURE 21

8 Model Results

When we implemented the fleet mix model with truck availability set to 50 for all truck types, the results were as expected. The optimization chose to use trucks with the most bang-for-the-buck, i.e. trucks with the most capacity per dollar/mile. Since there is practically no difference in the cost per mile of the tractor trailers ($0.75/mile), and there is a difference in their capacities, the optimization chose the largest trailer the most often. For the projected pallet demands at each location, 12 trailers were needed. The next most used truck type was the straight truck. 4 straight trucks were needed to meet projected demands. The two smallest trailers were not used at all.

These results confirm intuition that The Washington Post has had for a long time. In time, the future fleet will consist of straight trucks and large trailers. It is possible that due to accessibility limitations at certain distribution centers that specific truck types will be needed at specific locations, however, this was not taken into consideration in our model.

Appendix A: Acronyms

GMU – George Mason University

POC- Point of Contact

SEOR – Systems Engineering and Operation Research

WP – Washington Post

WPCD – Washington Post Circulations Department

WPPF – Washington Post Production Facility

VRP – Vehicle Routing Problem

Appendix B: References

1. T. Etezadi and J. E. Beasley. *Vehicle Fleet Composition*. The Journal of the Operational Research Society, Vol. 34, No. 1 (Jan., 1983), pp. 87-91
2. J. Privé , J. Renaud, F. Boctor, G. Laporte. *Solving a Vehicle-Routing Problem Arising in Soft-Drink Distribution.* The Journal of the Operational Research Society, Vol. 57, No. 9 (Sep., 2006), pp. 1045- 1052
3. F.-H. Liu and S.-Y. Shen.*The Fleet Size and Mix Vehicle Routing Problem with Time Windows.* The Journal of the Operational Research Society, Vol. 50, No. 7 (Jul., 1999), pp. 721- 732
4. M. Durbin and K. Hoffman. *The Dance of the Thirty-Ton Trucks: Dispatching and Scheduling in a Dynamic Environment.* Journal of Operations Research Vol. 56, No. 1, January–February 2008, pp. 3–19

Appendix C: Truck Routing Model Input Data

Destination	Product ID	8/16/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Full Press Run	5	8/16/2011 1:17	8/16/2011 4:00
ANNAPOLIS	Full Press Run	6	8/15/2011 22:40	8/16/2011 4:00
ARLINGTON	Full Press Run	4	8/15/2011 22:55	8/16/2011 4:00
ANNAPOLIS JUNCTION	Full Press Run	3	8/15/2011 23:00	8/16/2011 4:00
BOWIE	Full Press Run	5	8/15/2011 23:40	8/16/2011 4:00
BURKE	Full Press Run	8	8/16/2011 0:51	8/16/2011 4:00
CHANTILLY	Full Press Run	8	8/16/2011 0:00	8/16/2011 4:00
COLUMBIA	Full Press Run	9	8/16/2011 0:21	8/16/2011 4:00
DERWOOD	Full Press Run	13	8/16/2011 0:46	8/16/2011 4:00
DUNKIRK	Full Press Run	0		
FREDERICK	Full Press Run	4	8/15/2011 23:19	8/16/2011 4:00
GERMANTOWN	Full Press Run	6	8/15/2011 23:00	8/16/2011 4:00
HOLLYWOOD	Full Press Run	1	8/15/2011 22:55	8/16/2011 4:00
HYATTSVILLE	Full Press Run	8	8/15/2011 22:25	8/16/2011 4:00
LEESBURG	Full Press Run	0		
MANASSAS	Full Press Run	4	8/15/2011 22:25	8/16/2011 4:00
OXON HILL	Full Press Run	3	8/16/2011 0:51	8/16/2011 4:00
PURCELLVILLE	Full Press Run	0		
ROCKVILLE	Full Press Run	9	8/16/2011 0:51	8/16/2011 4:00
SEAT PLEASANT	Full Press Run	3	8/15/2011 22:55	8/16/2011 4:00
SOUTH DAKOTA	Full Press Run	9	8/15/2011 23:42	8/16/2011 4:00
SPRINGFIELD	Full Press Run	5	8/16/2011 1:46	8/16/2011 4:00
STERLING	Full Press Run	6	8/15/2011 22:25	8/16/2011 4:00
VIENNA	Full Press Run	9	8/16/2011 1:54	8/16/2011 4:00
WALDORF	Full Press Run	4	8/15/2011 22:55	8/16/2011 4:00
WARRENTON	Full Press Run	0		
WHITE OAK	Full Press Run	4	8/16/2011 0:51	8/16/2011 4:00
WOODBRIDGE	Full Press Run	3	8/15/2011 23:06	8/16/2011 4:00
ALEXANDRIA	Ads	10	8/15/2011 22:25	8/16/2011 4:00
ANNAPOLIS	Ads	11	8/15/2011 21:55	8/16/2011 4:00
ARLINGTON	Ads	0		
ANNAPOLIS JUNCTION	Ads	9	8/15/2011 20:09	8/16/2011 4:00
BOWIE	Ads	11	8/15/2011 20:38	8/16/2011 4:00
BURKE	Ads	22	8/15/2011 23:02	8/16/2011 4:00
CHANTILLY	Ads	23	8/16/2011 1:04	8/16/2011 4:00
COLUMBIA	Ads	20	8/15/2011 20:54	8/16/2011 4:00
DERWOOD	Ads	24	8/15/2011 23:43	8/16/2011 4:00
DUNKIRK	Ads	2	8/15/2011 19:24	8/16/2011 4:00
FREDERICK	Ads	9	8/15/2011 20:26	8/16/2011 4:00
GERMANTOWN	Ads	22	8/15/2011 19:36	8/16/2011 4:00
HOLLYWOOD	Ads	6	8/15/2011 20:21	8/16/2011 4:00
HYATTSVILLE	Ads	2	8/15/2011 22:15	8/16/2011 4:00
LEESBURG	Ads	0		
MANASSAS	Ads	18	8/15/2011 20:56	8/16/2011 4:00
OXON HILL	Ads	5	8/15/2011 20:09	8/16/2011 4:00
PURCELLVILLE	Ads	10	8/15/2011 21:58	8/16/2011 4:00
ROCKVILLE	Ads	3	8/15/2011 22:30	8/16/2011 4:00
SEAT PLEASANT	Ads	4	8/15/2011 20:50	8/16/2011 4:00
SOUTH DAKOTA	Ads	0		
SPRINGFIELD	Ads	12	8/15/2011 22:21	8/16/2011 4:00
STERLING	Ads	22	8/16/2011 1:40	8/16/2011 4:00
VIENNA	Ads	7	8/16/2011 0:12	8/16/2011 4:00
WALDORF	Ads	15	8/15/2011 21:22	8/16/2011 4:00
WARRENTON	Ads	4	8/15/2011 22:20	8/16/2011 4:00
WHITE OAK	Ads	13	8/15/2011 19:13	8/16/2011 4:00
WOODBRIDGE	Ads	13	8/15/2011 20:15	8/16/2011 4:00
ALEXANDRIA	Sunday Ad Pack			
ANNAPOLIS	Sunday Ad Pack			
ARLINGTON	Sunday Ad Pack	38	8/16/2011 9:32	8/21/2011 4:00
ANNAPOLIS JUNCTION	Sunday Ad Pack			
BOWIE	Sunday Ad Pack			
BURKE	Sunday Ad Pack			
CHANTILLY	Sunday Ad Pack			
COLUMBIA	Sunday Ad Pack			
DERWOOD	Sunday Ad Pack			
DUNKIRK	Sunday Ad Pack			
FREDERICK	Sunday Ad Pack	16	8/16/2011 11:11	8/21/2011 4:00
GERMANTOWN	Sunday Ad Pack			
HOLLYWOOD	Sunday Ad Pack			
HYATTSVILLE	Sunday Ad Pack			
LEESBURG	Sunday Ad Pack	17	8/16/2011 11:05	8/21/2011 4:00
MANASSAS	Sunday Ad Pack	35	8/15/2011 21:18	8/21/2011 4:00
OXON HILL	Sunday Ad Pack			
PURCELLVILLE	Sunday Ad Pack			
ROCKVILLE	Sunday Ad Pack			
SEAT PLEASANT	Sunday Ad Pack			
SOUTH DAKOTA	Sunday Ad Pack			
SPRINGFIELD	Sunday Ad Pack			
STERLING	Sunday Ad Pack			

VIENNA	Sunday Ad Pack			
WALDORF	Sunday Ad Pack			
WARRENTON	Sunday Ad Pack			
WHITE OAK	Sunday Ad Pack			
WOODBRIDGE	Sunday Ad Pack	29	8/16/2011 14:49	8/21/2011 4:00

Destination	Product ID	8/17/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Full Press Run	4	8/17/2011 1:17	8/17/2011 4:00
ANNAPOLIS	Full Press Run	6	8/16/2011 22:40	8/17/2011 4:00
ARLINGTON	Full Press Run	4	8/16/2011 22:55	8/17/2011 4:00
ANNAPOLIS JUNCTION	Full Press Run	3	8/16/2011 23:00	8/17/2011 4:00
BOWIE	Full Press Run	6	8/16/2011 23:40	8/17/2011 4:00
BURKE	Full Press Run	8	8/17/2011 0:51	8/17/2011 4:00
CHANTILLY	Full Press Run	5	8/17/2011 0:00	8/17/2011 4:00
COLUMBIA	Full Press Run	8	8/17/2011 0:21	8/17/2011 4:00
DERWOOD	Full Press Run	12	8/17/2011 0:46	8/17/2011 4:00
DUNKIRK	Full Press Run	0		
FREDERICK	Full Press Run	4	8/16/2011 23:19	8/17/2011 4:00
GERMANTOWN	Full Press Run	6	8/16/2011 23:00	8/17/2011 4:00
HOLLYWOOD	Full Press Run	1	8/16/2011 22:55	8/17/2011 4:00
HYATTSVILLE	Full Press Run	6	8/16/2011 22:25	8/17/2011 4:00
LEESBURG	Full Press Run	0		
MANASSAS	Full Press Run	3	8/16/2011 22:25	8/17/2011 4:00
OXON HILL	Full Press Run	3	8/17/2011 0:51	8/17/2011 4:00
PURCELLVILLE	Full Press Run	0		
ROCKVILLE	Full Press Run	10	8/17/2011 0:51	8/17/2011 4:00
SEAT PLEASANT	Full Press Run	3	8/16/2011 22:55	8/17/2011 4:00
SOUTH DAKOTA	Full Press Run	9	8/16/2011 23:42	8/17/2011 4:00
SPRINGFIELD	Full Press Run	4	8/17/2011 1:46	8/17/2011 4:00
STERLING	Full Press Run	4	8/16/2011 22:25	8/17/2011 4:00
VIENNA	Full Press Run	7	8/17/2011 1:54	8/17/2011 4:00
WALDORF	Full Press Run	4	8/16/2011 22:55	8/17/2011 4:00
WARRENTON	Full Press Run	0		
WHITE OAK	Full Press Run	4	8/16/2011 0:51	8/17/2011 4:00
WOODBRIDGE	Full Press Run	2	8/15/2011 23:06	8/17/2011 4:00
ALEXANDRIA	Ads	10	8/15/2011 22:25	8/17/2011 4:00
ANNAPOLIS	Ads	13	8/16/2011 21:55	8/17/2011 4:00
ARLINGTON	Ads	8	8/16/2011 21:35	8/17/2011 4:00
ANNAPOLIS JUNCTION	Ads	8	8/16/2011 20:09	8/17/2011 4:00
BOWIE	Ads	8	8/16/2011 20:38	8/17/2011 4:00
BURKE	Ads	9	8/16/2011 23:02	8/17/2011 4:00
CHANTILLY	Ads	10	8/17/2011 1:04	8/17/2011 4:00
COLUMBIA	Ads	19	8/16/2011 20:54	8/17/2011 4:00
DERWOOD	Ads	17	8/16/2011 23:43	8/17/2011 4:00
DUNKIRK	Ads	2	8/16/2011 19:24	8/17/2011 4:00
FREDERICK	Ads	7	8/16/2011 20:26	8/17/2011 4:00
GERMANTOWN	Ads	11	8/16/2011 19:36	8/17/2011 4:00
HOLLYWOOD	Ads	5	8/16/2011 20:21	8/17/2011 4:00
HYATTSVILLE	Ads	13	8/16/2011 22:15	8/17/2011 4:00
LEESBURG	Ads	0		
MANASSAS	Ads	6	8/16/2011 20:56	8/17/2011 4:00
OXON HILL	Ads	6	8/16/2011 20:09	8/17/2011 4:00
PURCELLVILLE	Ads	7	8/16/2011 21:58	8/17/2011 4:00
ROCKVILLE	Ads	13	8/16/2011 22:30	8/17/2011 4:00
SEAT PLEASANT	Ads	3	8/16/2011 20:50	8/17/2011 4:00
SOUTH DAKOTA	Ads	18	8/16/2011 20:15	8/17/2011 4:00
SPRINGFIELD	Ads	7	8/16/2011 22:21	8/17/2011 4:00
STERLING	Ads	6	8/17/2011 1:40	8/17/2011 4:00
VIENNA	Ads	13	8/17/2011 0:12	8/17/2011 4:00
WALDORF	Ads	14	8/16/2011 21:22	8/17/2011 4:00
WARRENTON	Ads	5	8/16/2011 22:20	8/17/2011 4:00
WHITE OAK	Ads	7	8/16/2011 19:13	8/17/2011 4:00
WOODBRIDGE	Ads	6	8/16/2011 19:01	8/17/2011 4:00
ALEXANDRIA	Sunday Ad Pack			
ANNAPOLIS	Sunday Ad Pack	32	8/17/2011 11:40	8/21/2011 4:00
ARLINGTON	Sunday Ad Pack			
ANNAPOLIS JUNCTION	Sunday Ad Pack			
BOWIE	Sunday Ad Pack			
BURKE	Sunday Ad Pack	54	8/17/2011 6:29	8/21/2011 4:00
CHANTILLY	Sunday Ad Pack	57	8/16/2011 19:22	8/21/2011 4:00
COLUMBIA	Sunday Ad Pack			
DERWOOD	Sunday Ad Pack			
DUNKIRK	Sunday Ad Pack	12	8/17/2011 11:07	8/21/2011 4:00
FREDERICK	Sunday Ad Pack			
GERMANTOWN	Sunday Ad Pack			
HOLLYWOOD	Sunday Ad Pack	16	8/17/2011 13:17	8/21/2011 4:00
HYATTSVILLE	Sunday Ad Pack			
LEESBURG	Sunday Ad Pack			
MANASSAS	Sunday Ad Pack			
OXON HILL	Sunday Ad Pack			

PURCELLVILLE	Sunday Ad Pack			
ROCKVILLE	Sunday Ad Pack			
SEAT PLEASANT	Sunday Ad Pack			
SOUTH DAKOTA	Sunday Ad Pack			
SPRINGFIELD	Sunday Ad Pack			
STERLING	Sunday Ad Pack	51	8/16/2011 17:00	8/21/2011 4:00
VIENNA	Sunday Ad Pack	61	8/17/2011 13:09	8/21/2011 4:00
WALDORF	Sunday Ad Pack	38	8/16/2011 17:26	8/21/2011 4:00
WARRENTON	Sunday Ad Pack	10	8/16/2011 22:22	8/21/2011 4:00
WHITE OAK	Sunday Ad Pack			
WOODBRIDGE	Sunday Ad Pack			

Destination	Product ID	8/18/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Full Press Run	5	8/18/2011 1:17	8/18/2011 4:00
ANNAPOLIS	Full Press Run	6	8/17/2011 22:40	8/18/2011 4:00
ARLINGTON	Full Press Run	4	8/17/2011 22:55	8/18/2011 4:00
ANNAPOLIS JUNCTION	Full Press Run	3	8/17/2011 23:00	8/18/2011 4:00
BOWIE	Full Press Run	6	8/17/2011 23:40	8/18/2011 4:00
BURKE	Full Press Run	8	8/18/2011 0:51	8/18/2011 4:00
CHANTILLY	Full Press Run	8	8/18/2011 0:00	8/18/2011 4:00
COLUMBIA	Full Press Run	9	8/18/2011 0:21	8/18/2011 4:00
DERWOOD	Full Press Run	13	8/18/2011 0:46	8/18/2011 4:00
DUNKIRK	Full Press Run	0		
FREDERICK	Full Press Run	4	8/17/2011 23:19	8/18/2011 4:00
GERMANTOWN	Full Press Run	6	8/17/2011 23:00	8/18/2011 4:00
HOLLYWOOD	Full Press Run	1	8/17/2011 22:55	8/18/2011 4:00
HYATTSVILLE	Full Press Run	8	8/17/2011 22:25	8/18/2011 4:00
LEESBURG	Full Press Run	0		
MANASSAS	Full Press Run	4	8/17/2011 22:25	8/18/2011 4:00
OXON HILL	Full Press Run	3	8/18/2011 0:51	8/18/2011 4:00
PURCELLVILLE	Full Press Run	0		
ROCKVILLE	Full Press Run	10	8/18/2011 0:51	8/18/2011 4:00
SEAT PLEASANT	Full Press Run	3	8/17/2011 22:55	8/18/2011 4:00
SOUTH DAKOTA	Full Press Run	9	8/17/2011 23:42	8/18/2011 4:00
SPRINGFIELD	Full Press Run	5	8/18/2011 1:46	8/18/2011 4:00
STERLING	Full Press Run	6	8/17/2011 22:25	8/18/2011 4:00
VIENNA	Full Press Run	9	8/18/2011 1:54	8/18/2011 4:00
WALDORF	Full Press Run	4	8/17/2011 22:55	8/18/2011 4:00
WARRENTON	Full Press Run	0		
WHITE OAK	Full Press Run	4	8/18/2011 0:51	8/18/2011 4:00
WOODBRIDGE	Full Press Run	3	8/17/2011 23:06	8/18/2011 4:00
ALEXANDRIA	Ads	8	8/17/2011 20:46	8/18/2011 4:00
ANNAPOLIS	Ads	13	8/17/2011 21:39	8/18/2011 4:00
ARLINGTON	Ads	6	8/17/2011 21:44	8/18/2011 4:00
ANNAPOLIS JUNCTION	Ads	7	8/17/2011 21:03	8/18/2011 4:00
BOWIE	Ads	8	8/17/2011 20:18	8/18/2011 4:00
BURKE	Ads	11	8/17/2011 20:23	8/18/2011 4:00
CHANTILLY	Ads	11	8/17/2011 20:48	8/18/2011 4:00
COLUMBIA	Ads	16	8/17/2011 20:54	8/18/2011 4:00
DERWOOD	Ads	17	8/17/2011 20:33	8/18/2011 4:00
DUNKIRK	Ads	6	8/17/2011 19:20	8/18/2011 4:00
FREDERICK	Ads	5	8/17/2011 20:39	8/18/2011 4:00
GERMANTOWN	Ads	10	8/17/2011 19:31	8/18/2011 4:00
HOLLYWOOD	Ads	4	8/17/2011 20:16	8/18/2011 4:00
HYATTSVILLE	Ads	11	8/17/2011 21:16	8/18/2011 4:00
LEESBURG	Ads	0		
MANASSAS	Ads	8	8/17/2011 21:11	8/18/2011 4:00
OXON HILL	Ads	4	8/17/2011 20:33	8/18/2011 4:00
PURCELLVILLE	Ads	14	8/17/2011 21:26	8/18/2011 4:00
ROCKVILLE	Ads	12	8/17/2011 19:25	8/18/2011 4:00
SEAT PLEASANT	Ads	3	8/17/2011 20:59	8/18/2011 4:00
SOUTH DAKOTA	Ads	15	8/17/2011 20:33	8/18/2011 4:00
SPRINGFIELD	Ads	9	8/17/2011 20:25	8/18/2011 4:00
STERLING	Ads	11	8/17/2011 20:28	8/18/2011 4:00
VIENNA	Ads	13	8/17/2011 20:46	8/18/2011 4:00
WALDORF	Ads	12	8/17/2011 21:17	8/18/2011 4:00
WARRENTON	Ads	5	8/17/2011 22:31	8/18/2011 4:00
WHITE OAK	Ads	7	8/17/2011 19:14	8/18/2011 4:00
WOODBRIDGE	Ads	5	8/17/2011 20:37	8/18/2011 4:00
ALEXANDRIA	Sunday Ad Pack			
ANNAPOLIS	Sunday Ad Pack			
ARLINGTON	Sunday Ad Pack			
ANNAPOLIS JUNCTION	Sunday Ad Pack			
BOWIE	Sunday Ad Pack			
BURKE	Sunday Ad Pack			
CHANTILLY	Sunday Ad Pack			
COLUMBIA	Sunday Ad Pack	36	8/17/2011 16:57	8/21/2011 4:00
DERWOOD	Sunday Ad Pack	68	8/17/2011 20:34	8/21/2011 4:00
DUNKIRK	Sunday Ad Pack			
FREDERICK	Sunday Ad Pack			

GERMANTOWN	Sunday Ad Pack			
HOLLYWOOD	Sunday Ad Pack			
HYATTSVILLE	Sunday Ad Pack	55	8/17/2011 18:18	8/21/2011 4:00
LEESBURG	Sunday Ad Pack			
MANASSAS	Sunday Ad Pack			
OXON HILL	Sunday Ad Pack			
PURCELLVILLE	Sunday Ad Pack			
ROCKVILLE	Sunday Ad Pack			
SEAT PLEASANT	Sunday Ad Pack			
SOUTH DAKOTA	Sunday Ad Pack			
SPRINGFIELD	Sunday Ad Pack			
STERLING	Sunday Ad Pack			
VIENNA	Sunday Ad Pack			
WALDORF	Sunday Ad Pack			
WARRENTON	Sunday Ad Pack			
WHITE OAK	Sunday Ad Pack	32	8/18/2011 12:55	8/21/2011 4:00
WOODBRIDGE	Sunday Ad Pack			

Destination	Product ID	8/19/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Full Press Run	6	8/19/2011 1:17	8/19/2011 4:00
ANNAPOLIS	Full Press Run	6	8/18/2011 22:40	8/19/2011 4:00
ARLINGTON	Full Press Run	4	8/18/2011 22:55	8/19/2011 4:00
ANNAPOLIS JUNCTION	Full Press Run	3	8/18/2011 23:00	8/19/2011 4:00
BOWIE	Full Press Run	7	8/18/2011 23:40	8/19/2011 4:00
BURKE	Full Press Run	8	8/19/2011 0:51	8/19/2011 4:00
CHANTILLY	Full Press Run	8	8/19/2011 0:00	8/19/2011 4:00
COLUMBIA	Full Press Run	9	8/19/2011 0:21	8/19/2011 4:00
DERWOOD	Full Press Run	13	8/19/2011 0:46	8/19/2011 4:00
DUNKIRK	Full Press Run	0		
FREDERICK	Full Press Run	4	8/18/2011 23:19	8/19/2011 4:00
GERMANTOWN	Full Press Run	6	8/18/2011 23:00	8/19/2011 4:00
HOLLYWOOD	Full Press Run	1	8/18/2011 22:55	8/19/2011 4:00
HYATTSVILLE	Full Press Run	8	8/18/2011 22:25	8/19/2011 4:00
LEESBURG	Full Press Run	0		
MANASSAS	Full Press Run	4	8/18/2011 22:25	8/19/2011 4:00
OXON HILL	Full Press Run	4	8/18/2011 0:51	8/19/2011 4:00
PURCELLVILLE	Full Press Run	0		
ROCKVILLE	Full Press Run	10	8/19/2011 0:51	8/19/2011 4:00
SEAT PLEASANT	Full Press Run	3	8/18/2011 22:55	8/19/2011 4:00
SOUTH DAKOTA	Full Press Run	9	8/18/2011 23:42	8/19/2011 4:00
SPRINGFIELD	Full Press Run	6	8/19/2011 1:46	8/19/2011 4:00
STERLING	Full Press Run	7	8/18/2011 22:25	8/19/2011 4:00
VIENNA	Full Press Run	12	8/19/2011 1:54	8/19/2011 4:00
WALDORF	Full Press Run	4	8/18/2011 22:55	8/19/2011 4:00
WARRENTON	Full Press Run	0		
WHITE OAK	Full Press Run	5	8/19/2011 0:51	8/19/2011 4:00
WOODBRIDGE	Full Press Run	4	8/18/2011 23:06	8/19/2011 4:00
ALEXANDRIA	Ads	5	8/18/2011 19:28	8/19/2011 4:00
ANNAPOLIS	Ads	8	8/18/2011 22:17	8/19/2011 4:00
ARLINGTON	Ads	6	8/18/2011 20:20	8/19/2011 4:00
ANNAPOLIS JUNCTION	Ads	4	8/18/2011 21:04	8/19/2011 4:00
BOWIE	Ads	7	8/18/2011 21:23	8/19/2011 4:00
BURKE	Ads	8	8/18/2011 19:32	8/19/2011 4:00
CHANTILLY	Ads	8	8/18/2011 21:30	8/19/2011 4:00
COLUMBIA	Ads	9	8/18/2011 21:52	8/19/2011 4:00
DERWOOD	Ads	16	8/18/2011 23:41	8/19/2011 4:00
DUNKIRK	Ads	2	8/18/2011 18:35	8/19/2011 4:00
FREDERICK	Ads	5	8/18/2011 20:46	8/19/2011 4:00
GERMANTOWN	Ads	7	8/18/2011 20:02	8/19/2011 4:00
HOLLYWOOD	Ads	2	8/18/2011 21:09	8/19/2011 4:00
HYATTSVILLE	Ads	8	8/18/2011 22:17	8/19/2011 4:00
LEESBURG	Ads	0		
MANASSAS	Ads	4	8/18/2011 21:42	8/19/2011 4:00
OXON HILL	Ads	3	8/18/2011 20:23	8/19/2011 4:00
PURCELLVILLE	Ads	10	8/18/2011 21:41	8/19/2011 4:00
ROCKVILLE	Ads	11	8/18/2011 20:48	8/19/2011 4:00
SEAT PLEASANT	Ads	3	8/18/2011 20:48	8/19/2011 4:00
SOUTH DAKOTA	Ads	10	8/18/2011 19:52	8/19/2011 4:00
SPRINGFIELD	Ads	5	8/18/2011 19:43	8/19/2011 4:00
STERLING	Ads	7	8/18/2011 21:11	8/19/2011 4:00
VIENNA	Ads	12	8/18/2011 21:35	8/19/2011 4:00
WALDORF	Ads	9	8/18/2011 22:17	8/19/2011 4:00
WARRENTON	Ads	3	8/18/2011 22:30	8/19/2011 4:00
WHITE OAK	Ads	6	8/18/2011 20:28	8/19/2011 4:00
WOODBRIDGE	Ads	3	8/18/2011 20:32	8/19/2011 4:00
ALEXANDRIA	Sunday Ad Pack			
ANNAPOLIS	Sunday Ad Pack			
ARLINGTON	Sunday Ad Pack			
ANNAPOLIS JUNCTION	Sunday Ad Pack			
BOWIE	Sunday Ad Pack	27	8/18/2011 15:59	8/21/2011 4:00

BURKE	Sunday Ad Pack			
CHANTILLY	Sunday Ad Pack			
COLUMBIA	Sunday Ad Pack			
DERWOOD	Sunday Ad Pack			
DUNKIRK	Sunday Ad Pack			
FREDERICK	Sunday Ad Pack			
GERMANTOWN	Sunday Ad Pack	49	8/18/2011 19:56	8/21/2011 4:00
HOLLYWOOD	Sunday Ad Pack			
HYATTSVILLE	Sunday Ad Pack			
LEESBURG	Sunday Ad Pack			
MANASSAS	Sunday Ad Pack			
OXON HILL	Sunday Ad Pack	30	8/18/2011 16:31	8/21/2011 4:00
PURCELLVILLE	Sunday Ad Pack			
ROCKVILLE	Sunday Ad Pack			
SEAT PLEASANT	Sunday Ad Pack	27	8/18/2011 19:24	8/21/2011 4:00
SOUTH DAKOTA	Sunday Ad Pack			
SPRINGFIELD	Sunday Ad Pack			
STERLING	Sunday Ad Pack			
VIENNA	Sunday Ad Pack			
WALDORF	Sunday Ad Pack			
WARRENTON	Sunday Ad Pack			
WHITE OAK	Sunday Ad Pack			
WOODBRIDGE	Sunday Ad Pack			

Destination	Product ID	8/20/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Full Press Run	5	8/20/2011 1:17	8/20/2011 4:00
ANNAPOLIS	Full Press Run	6	8/19/2011 22:40	8/20/2011 4:00
ARLINGTON	Full Press Run	3	8/19/2011 22:55	8/20/2011 4:00
ANNAPOLIS JUNCTION	Full Press Run	3	8/19/2011 23:00	8/20/2011 4:00
BOWIE	Full Press Run	6	8/19/2011 23:40	8/20/2011 4:00
BURKE	Full Press Run	8	8/20/2011 0:51	8/20/2011 4:00
CHANTILLY	Full Press Run	8	8/20/2011 0:00	8/20/2011 4:00
COLUMBIA	Full Press Run	9	8/20/2011 0:21	8/20/2011 4:00
DERWOOD	Full Press Run	13	8/20/2011 0:46	8/20/2011 4:00
DUNKIRK	Full Press Run	0		
FREDERICK	Full Press Run	4	8/19/2011 23:19	8/20/2011 4:00
GERMANTOWN	Full Press Run	6	8/19/2011 23:00	8/20/2011 4:00
HOLLYWOOD	Full Press Run	1	8/19/2011 22:55	8/20/2011 4:00
HYATTSVILLE	Full Press Run	8	8/19/2011 22:25	8/20/2011 4:00
LEESBURG	Full Press Run	0		
MANASSAS	Full Press Run	4	8/19/2011 22:25	8/20/2011 4:00
OXON HILL	Full Press Run	3	8/19/2011 0:51	8/20/2011 4:00
PURCELLVILLE	Full Press Run	0		
ROCKVILLE	Full Press Run	10	8/20/2011 0:51	8/20/2011 4:00
SEAT PLEASANT	Full Press Run	3	8/19/2011 22:55	8/20/2011 4:00
SOUTH DAKOTA	Full Press Run	9	8/19/2011 23:42	8/20/2011 4:00
SPRINGFIELD	Full Press Run	3	8/20/2011 1:46	8/20/2011 4:00
STERLING	Full Press Run	6	8/19/2011 22:25	8/20/2011 4:00
VIENNA	Full Press Run	9	8/20/2011 1:54	8/20/2011 4:00
WALDORF	Full Press Run	4	8/19/2011 22:55	8/20/2011 4:00
WARRENTON	Full Press Run	0		
WHITE OAK	Full Press Run	4	8/20/2011 0:51	8/20/2011 4:00
WOODBRIDGE	Full Press Run	3	8/19/2011 23:06	8/20/2011 4:00
ALEXANDRIA	Ads	5	8/19/2011 21:34	8/20/2011 4:00
ANNAPOLIS	Ads	5	8/19/2011 21:36	8/20/2011 4:00
ARLINGTON	Ads	2	8/19/2011 20:45	8/20/2011 4:00
ANNAPOLIS JUNCTION	Ads	3	8/19/2011 22:01	8/20/2011 4:00
BOWIE	Ads	6	8/19/2011 20:31	8/20/2011 4:00
BURKE	Ads	5	8/19/2011 21:13	8/20/2011 4:00
CHANTILLY	Ads	5	8/19/2011 21:42	8/20/2011 4:00
COLUMBIA	Ads	5	8/19/2011 22:36	8/20/2011 4:00
DERWOOD	Ads	8	8/20/2011 0:12	8/20/2011 4:00
DUNKIRK	Ads	2	8/19/2011 20:46	8/20/2011 4:00
FREDERICK	Ads	4	8/19/2011 20:22	8/20/2011 4:00
GERMANTOWN	Ads	3	8/19/2011 19:33	8/20/2011 4:00
HOLLYWOOD	Ads	2	8/19/2011 21:58	8/20/2011 4:00
HYATTSVILLE	Ads	5	8/19/2011 22:31	8/20/2011 4:00
LEESBURG	Ads	0		
MANASSAS	Ads	2	8/19/2011 19:56	8/20/2011 4:00
OXON HILL	Ads	3	8/19/2011 20:45	8/20/2011 4:00
PURCELLVILLE	Ads	4	8/19/2011 21:52	8/20/2011 4:00
ROCKVILLE	Ads	6	8/19/2011 22:53	8/20/2011 4:00
SEAT PLEASANT	Ads	2	8/19/2011 21:46	8/20/2011 4:00
SOUTH DAKOTA	Ads	9	8/19/2011 20:40	8/20/2011 4:00
SPRINGFIELD	Ads	3	8/19/2011 19:53	8/20/2011 4:00
STERLING	Ads	3	8/19/2011 20:20	8/20/2011 4:00
VIENNA	Ads	5	8/19/2011 21:19	8/20/2011 4:00
WALDORF	Ads	4	8/19/2011 23:04	8/20/2011 4:00
WARRENTON	Ads	1	8/19/2011 20:38	8/20/2011 4:00
WHITE OAK	Ads	3	8/19/2011 22:28	8/20/2011 4:00

WOODBRIDGE	Ads	2	8/19/2011 20:43	8/20/2011 4:00
ALEXANDRIA	Sunday Ad Pack			
ANNAPOLIS	Sunday Ad Pack			
ARLINGTON	Sunday Ad Pack			
ANNAPOLIS JUNCTION	Sunday Ad Pack	20	8/19/2011 22:01	8/21/2011 4:00
BOWIE	Sunday Ad Pack			
BURKE	Sunday Ad Pack			
CHANTILLY	Sunday Ad Pack			
COLUMBIA	Sunday Ad Pack			
DERWOOD	Sunday Ad Pack			
DUNKIRK	Sunday Ad Pack			
FREDERICK	Sunday Ad Pack			
GERMANTOWN	Sunday Ad Pack			
HOLLYWOOD	Sunday Ad Pack			
HYATTSVILLE	Sunday Ad Pack			
LEESBURG	Sunday Ad Pack			
MANASSAS	Sunday Ad Pack			
OXON HILL	Sunday Ad Pack			
PURCELLVILLE	Sunday Ad Pack			
ROCKVILLE	Sunday Ad Pack	66	8/19/2011 6:24	8/21/2011 4:00
SEAT PLEASANT	Sunday Ad Pack			
SOUTH DAKOTA	Sunday Ad Pack			
SPRINGFIELD	Sunday Ad Pack			
STERLING	Sunday Ad Pack			
VIENNA	Sunday Ad Pack			
WALDORF	Sunday Ad Pack			
WARRENTON	Sunday Ad Pack			
WHITE OAK	Sunday Ad Pack			
WOODBRIDGE	Sunday Ad Pack			

Destination	Product ID	8/20/2011 Pallets	Production Time	Delivery Time
ALEXANDRIA	Sunday Ad Pack	39	8/20/2011 19:41	8/21/2011 4:00
ANNAPOLIS	Sunday Ad Pack			
ARLINGTON	Sunday Ad Pack			
ANNAPOLIS JUNCTION	Sunday Ad Pack			
BOWIE	Sunday Ad Pack			
BURKE	Sunday Ad Pack			
CHANTILLY	Sunday Ad Pack			
COLUMBIA	Sunday Ad Pack			
DERWOOD	Sunday Ad Pack			
DUNKIRK	Sunday Ad Pack			
FREDERICK	Sunday Ad Pack			
GERMANTOWN	Sunday Ad Pack			
HOLLYWOOD	Sunday Ad Pack			
HYATTSVILLE	Sunday Ad Pack			
LEESBURG	Sunday Ad Pack			
MANASSAS	Sunday Ad Pack			
OXON HILL	Sunday Ad Pack			
PURCELLVILLE	Sunday Ad Pack	4	8/20/2011 15:49	8/21/2011 4:00
ROCKVILLE	Sunday Ad Pack			
SEAT PLEASANT	Sunday Ad Pack			
SOUTH DAKOTA	Sunday Ad Pack	52	8/20/2011 19:58	8/21/2011 4:00
SPRINGFIELD	Sunday Ad Pack	39	8/20/2011 18:48	8/21/2011 4:00
STERLING	Sunday Ad Pack			
VIENNA	Sunday Ad Pack			
WALDORF	Sunday Ad Pack			
WARRENTON	Sunday Ad Pack			
WHITE OAK	Sunday Ad Pack			
WOODBRIDGE	Sunday Ad Pack			

Appendix D: VRP Formulation

$N = \{0 \ldots n+1\}$: The set of nodes in the graph where nodes 0 and $n+1$ denote the production facility (depot) and the remaining n nodes denote distribution warehouses.

$K = \{\text{Truck Types}\}$: The set of truck types (straight, tractor, whatever). For each truck type $k \in K$, let k_t denote the t^{th} truck of type k. If we want to solve the problem for a fixed fleet, we can use the real number of each truck type that the Washington Post leases. When solving the optimal fleet composition problem, we can make the number of available trucks of each type large.

Q_k: The capacity (pallets) of truck type k.

$r \in \{1 \ldots R\}$: The route number. Each truck will be assigned to R routes in a tour. Null routes will be identified because they will start at node 0 and go directly to node $n+1$. Therefore, k_t^r refers to route r for the t^{th} truck of type k.

$X_{ij}^{k_t^r} \in \{0,1\}$: This binary variable corresponds to whether or not the arc between nodes $i, j \in N$ is used during route r for the t^{th} truck of type k.

$P = \{\text{Products}\}$: The set of products (headsheets, inserts, sunday advance, whatever) to be delivered to the warehouses.

$Y_{ij}^{k_t^r,p} \in \mathbb{Z}$: The integer number of product $p \in P$ that is carried between nodes $i, j \in N$ during route r for the t^{th} truck of type k.

D_i^p: The demand for product $p \in P$ and node $i \in \{1 \ldots n\}$. Let $\bar{D} = \max\{D_i^p\}$.

l_{ij}: The traveling time from node i to j. This also includes loading/unloading times. i.e. $l_{0,1}$ is the time it takes to load the truck at the depot and drive to warehouse 1. Assume that the traveling time is independent of truck type. Also note that $l_{0,n+1} = 0$.

$L_{k_t^r}$: The total time for the t^{th} truck of type k to complete route r.

$S_{k_t^r}$: The starting time for route r for the t^{th} truck of type k.

m_p: The time that product p is manufactured and ready to be transported.

$z_{k_t^r,p} \in \{0,1\}$: A binary variable used in the *If-Then* constraints.

F_{k_t}: The fixed cost for using the t^{th} truck of type k.

V_{ij}^k: The variable cost for using a truck of type k to travel from node i to j.

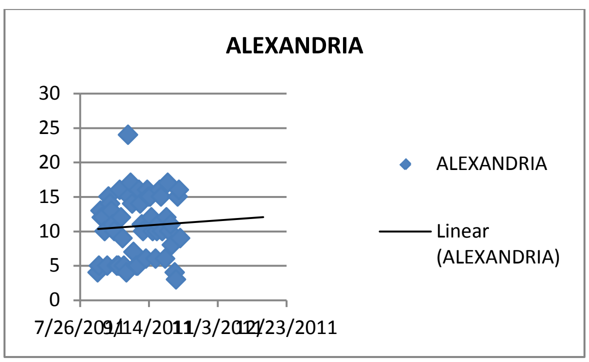
$$\min \sum_r \sum_k \sum_t \sum_{j=1}^{n} F_{k_t} X_{0,j}^{k_t^r} + \sum_r \sum_k \sum_t \sum_i \sum_j V_{ij}^k X_{ij}^{k_t^r} + \sum_r \sum_k \sum_t L_{k_t^r}$$

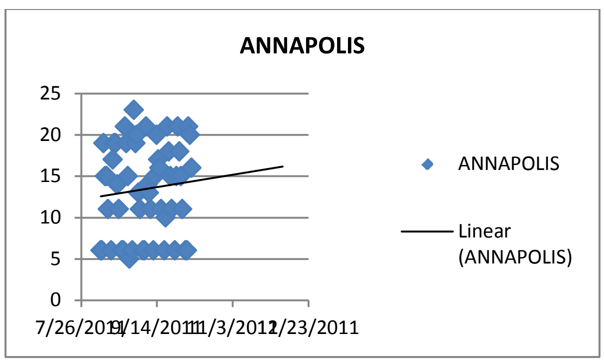
$$\begin{aligned}
\sum_{i=0}^{n} X_{i,n+1}^{k_t^r} &= 1 && \forall r,k,t && (1)\\
\sum_{j=1}^{n+1} X_{0,j}^{k_t^r} &= 1 && \forall r,k,t && (2)\\
\sum_{i=1}^{n} X_{i,j}^{k_t^r} &\leq 1 && \forall j \in \{1 \ldots n\} | i \neq j,\ \forall r,k,t && (3)\\
\sum_{j=1}^{n} X_{i,j}^{k_t^r} &\leq 1 && \forall i \in \{1 \ldots n\} | i \neq j,\ \forall r,k,t && (4)\\
\sum_p Y_{i,j}^{k_t^r} &\leq \bar{D} X_{i,j}^{k_t^r} && \forall i,j | i \neq j,\ \forall r,k,t && (5)\\
\sum_r \sum_k \sum_t \sum_i Y_{i,j}^{k_t^r} &= D_j^p && \forall j,p && (6)\\
\sum_i \sum_j \sum_p Y_{i,j}^{k_t^r} &\leq Q_k && \forall i \neq j, r,k,t && (7)\\
\sum_i \sum_j l_{i,j} X_{i,j}^{k_t^r} &= L_{k_t^r} && \forall i \neq j, r,k,t && (8)\\
S_{k_t^{r+1}} &\geq S_{k_t^r} + L_{k_t^r} && \forall r \in \{1 \ldots R-1\},\ \forall k,t && (9)\\
\sum_j Y_{0,j}^{k_t^r,p} &\leq \bar{D}(1 - z_{k_t^r}) && \forall r,k,t,p && (10)\\
-S_{k_t^r} + m_p &\leq \bar{D} z_{k_t^r} && \forall r,k,t,p && (11)\\
X_{i,j}^{k_t^r} \in \{0,1\},\ Y_{i,j}^{k_t^r,p}, S_{k_t^r} &\in \mathbb{Z}_+ && \forall i,j,k,t,r,p && (12)
\end{aligned}$$

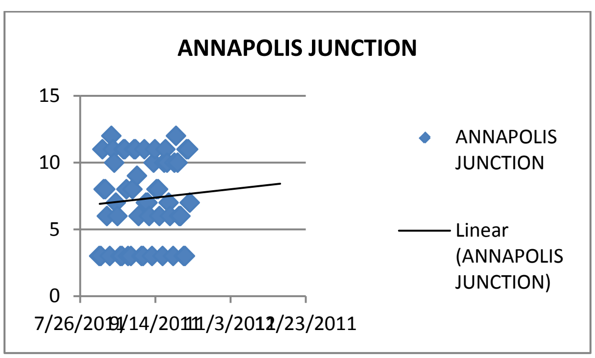
Constraints (1)-(4) are flow balance constraints for each truck route. (5) forces the model to pay to ship products. (6) is the set of demand constraints. (7) is the set of capacity constraints. (8) calculates the length of each route for each truck. (9) ensures that each route for each truck starts after the previous route ends. (10)-(11) ensures that if a route for a truck moves a product p, then that product must have been produced already.

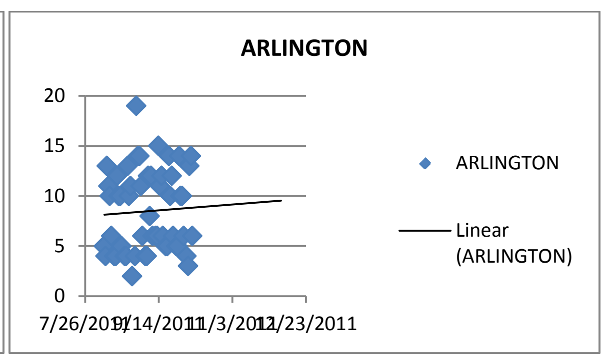
Appendix E: Fleet Mix Data

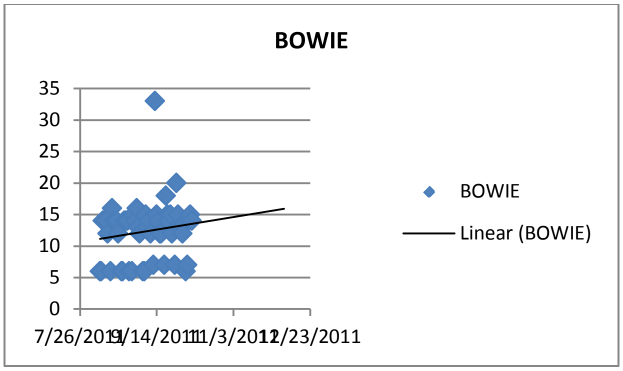
Destination	60 day Pallet Projection
ALEXANDRIA	11
ANNAPOLIS	16
ARLINGTON	9
ANNAPOLIS JUNCTION	8
BOWIE	16
BURKE	18
CHANTILLY	20
COLUMBIA	25
DERWOOD	30
DUNKIRK	3
FREDERICK	9
GERMANTOWN	17
HOLLYWOOD	4
HYATTSVILLE	20
LEESBURG	0
MANASSAS	14
OXON HILL	9
PURCELLVILLE	6
ROCKVILLE	45
SEAT PLEASANT	8
SOUTH DAKOTA	27
SPRINGFIELD	12
STERLING	19
VIENNA	22
WALDORF	12
WARRENTON	2
WHITE OAK	13
WOODBRIDGE	9

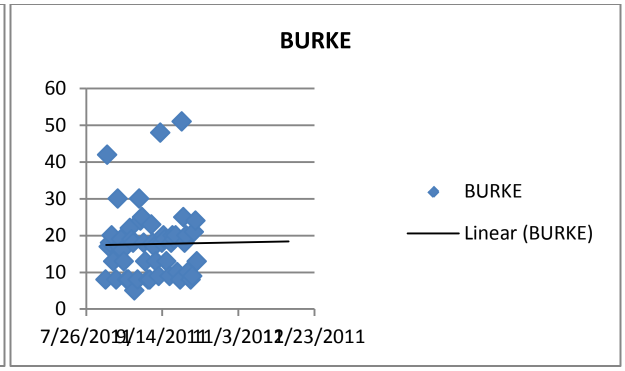


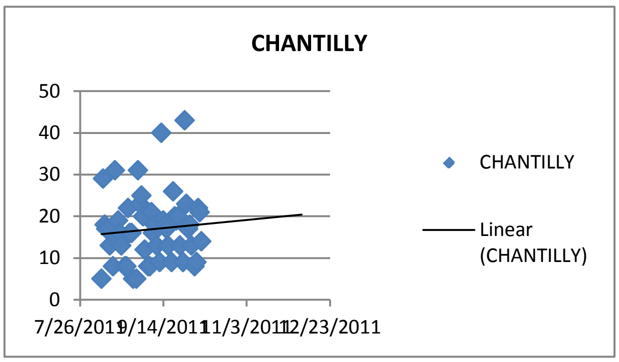


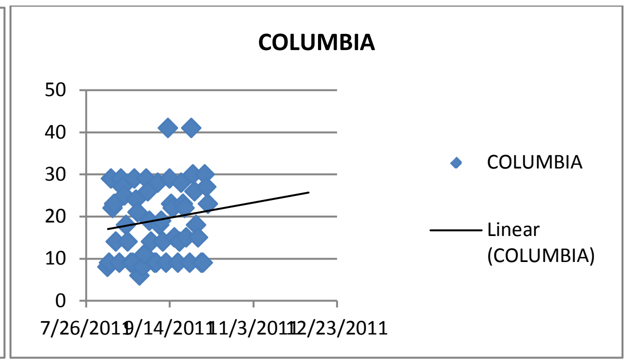


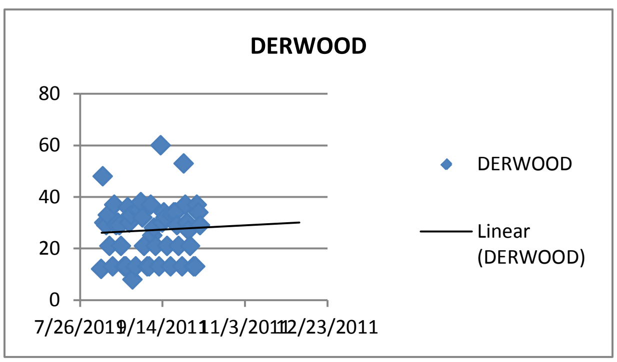


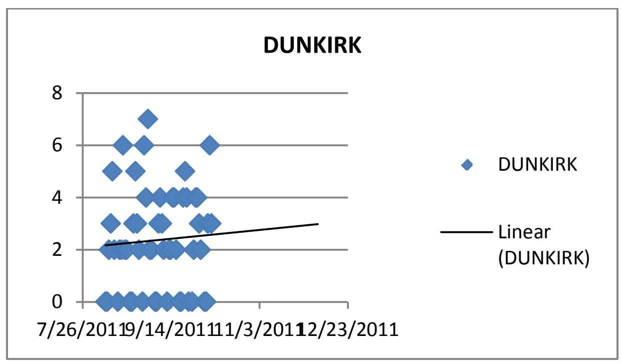

BOWIE
35
30
25
20
15
10
5
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
BOWIE
Linear (BOWIE)

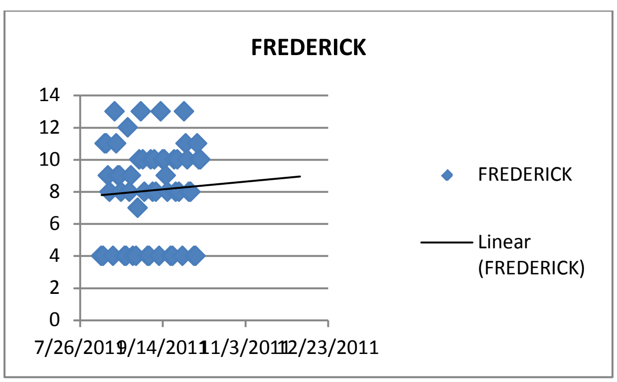

BURKE
60
50
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
BURKE
Linear (BURKE)

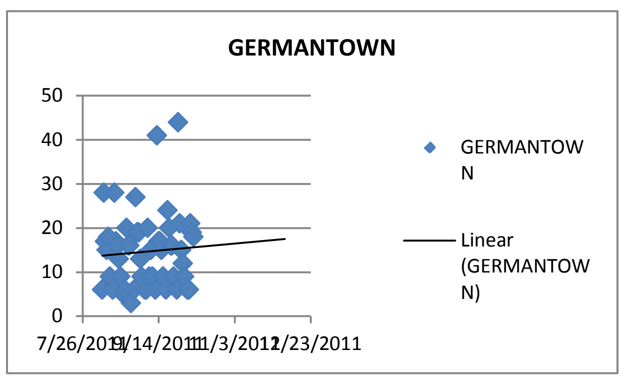

CHANTILLY
50
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
CHANTILLY
Linear (CHANTILLY)

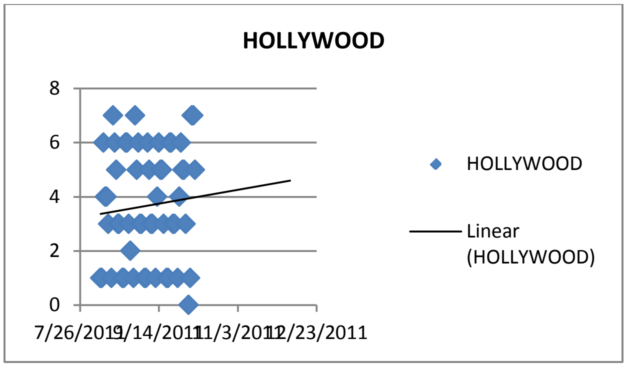

COLUMBIA
50
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
COLUMBIA
Linear (COLUMBIA)

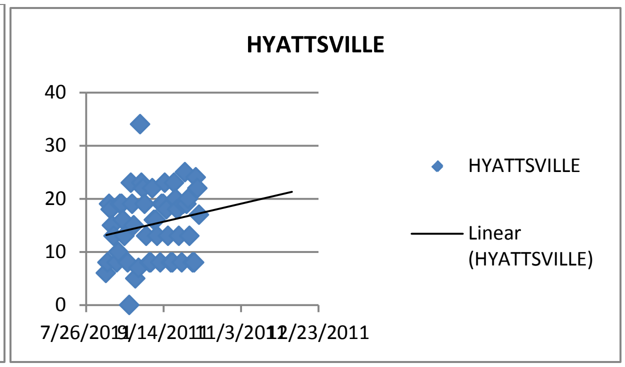

DERWOOD
80
60
40
20
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
DERWOOD
Linear (DERWOOD)

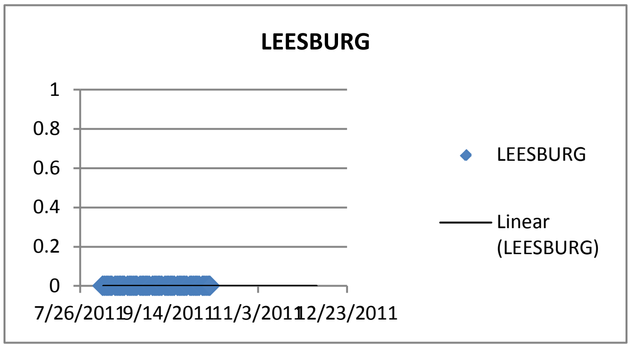

DUNKIRK
8
6
4
2
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
DUNKIRK
Linear (DUNKIRK)

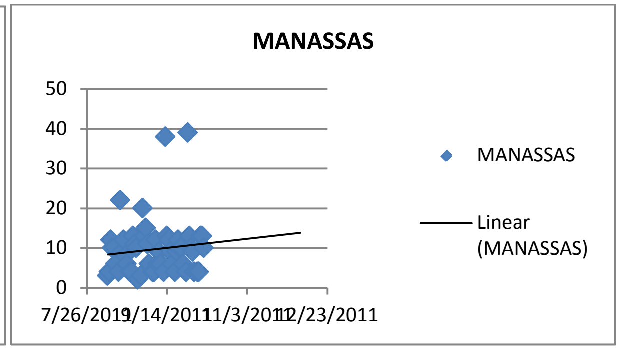

FREDERICK
14
12
10
8
6
4
2
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
FREDERICK
Linear (FREDERICK)

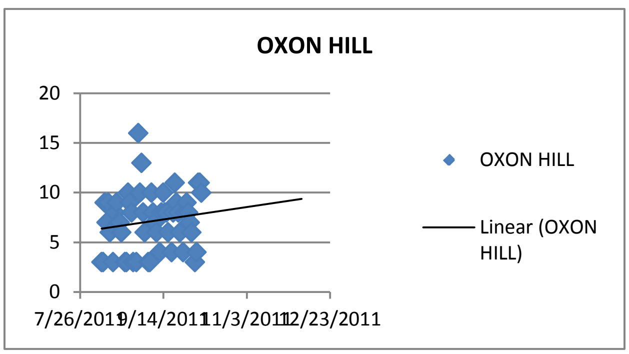

GERMANTOWN
50
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
GERMANTOWN
Linear (GERMANTOWN)

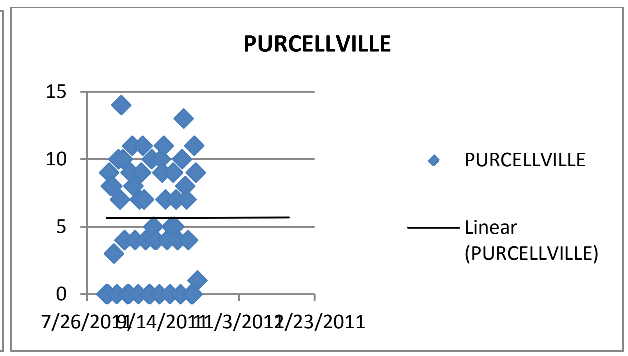

HOLLYWOOD
8
6
4
2
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
HOLLYWOOD
Linear (HOLLYWOOD)

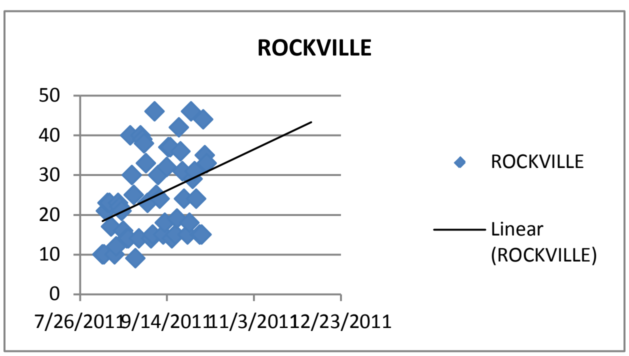

HYATTSVILLE
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
HYATTSVILLE
Linear (HYATTSVILLE)

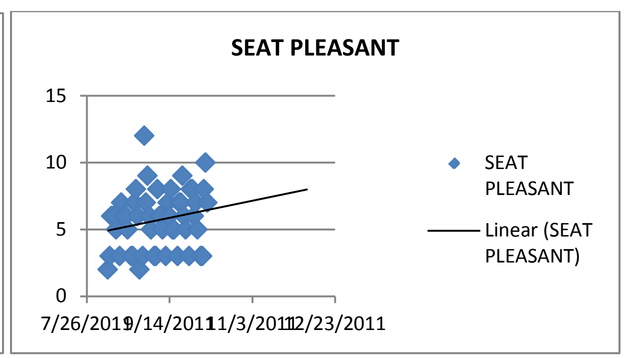

LEESBURG
1
0.8
0.6
0.4
0.2
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
LEESBURG
Linear (LEESBURG)

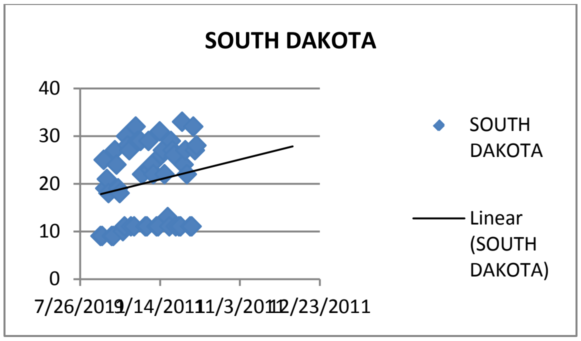

MANASSAS
50
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
MANASSAS
Linear (MANASSAS)


OXON HILL
20
15
10
5
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
OXON HILL
Linear (OXON HILL)

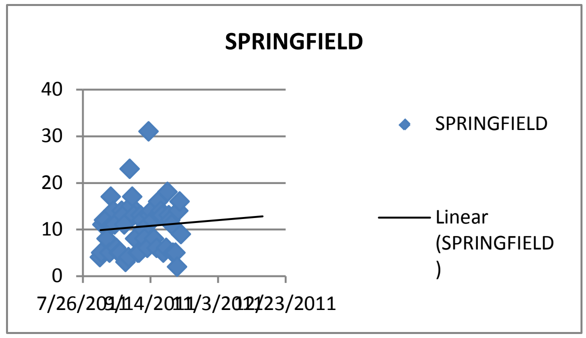

PURCELLVILLE
15
10
5
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
PURCELLVILLE
Linear (PURCELLVILLE)


ROCKVILLE
50
40
30
20
10
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
ROCKVILLE
Linear (ROCKVILLE)

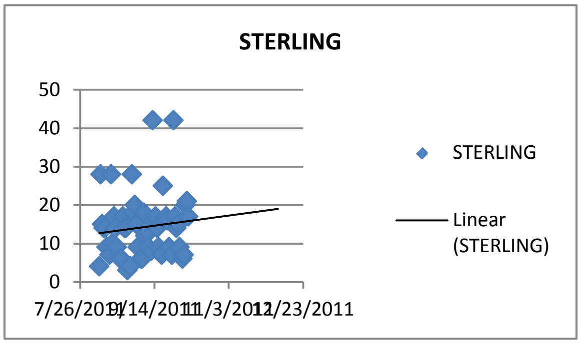

SEAT PLEASANT
15
10
5
0
7/26/2011
9/14/2011
11/3/2011
12/23/2011
SEAT PLEASANT
Linear (SEAT PLEASANT)



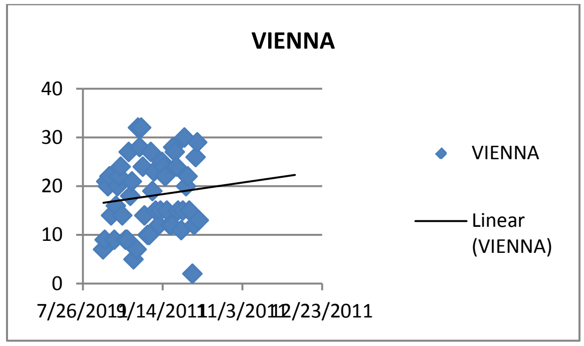
SOUTH DAKOTA
40
30
20
10
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
SOUTH DAKOTA
Linear (SOUTH DAKOTA)



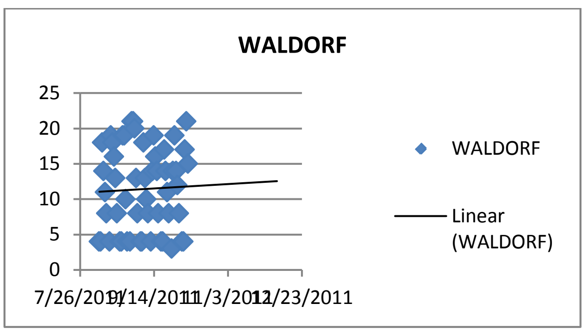
SPRINGFIELD
40
30
20
10
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
SPRINGFIELD
Linear (SPRINGFIELD)



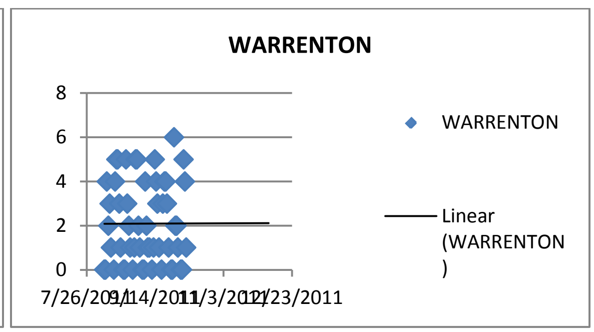
STERLING
50
40
30
20
10
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
STERLING
Linear (STERLING)



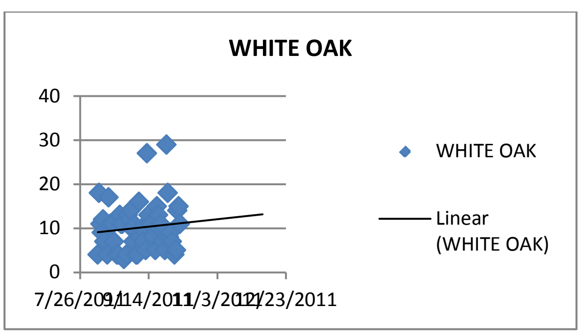
VIENNA
40
30
20
10
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
VIENNA
Linear (VIENNA)



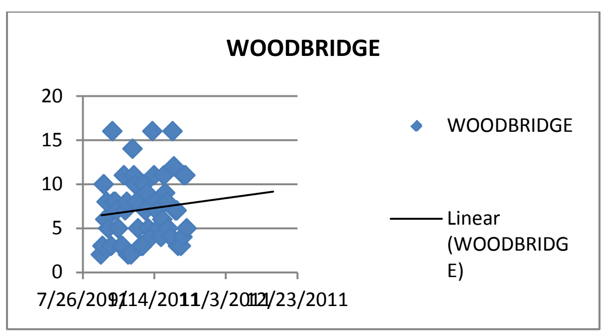
WALDORF
25
20
15
10
5
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
WALDORF
Linear (WALDORF)



WARRENTON
8
6
4
2
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
WARRENTON
Linear (WARRENTON)



WHITE OAK
40
30
20
10
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
WHITE OAK
Linear (WHITE OAK)



WOODBRIDGE
20
15
10
5
0
7/26/2011 9/14/2011 11/3/2011 12/23/2011
WOODBRIDGE
Linear (WOODBRIDG E)

Appendix F: Output Data

The following is a partial solution file for a Batch run.

```
   MPL Modeling System   -   Copyright (c) 1988-2011, Maximal Software, 
Inc.
--------------------------------------------------------------------------
------


MODEL STATISTICS

Problem name:       WP_BatchMPL (64-bit)

Filename:           WP_BatchMPL.mpl
Date:               November 29, 2011
Time:               21:42
Parsing time:       1.94 sec

Solver name:        CPLEX  (12.3.0.0)
Objective value:    127358.000000
MIP best bound:     63911.7685529
Integer nodes:      2375
Iterations:         348350
Solution time:      20 min, 1 sec
Result code:        107

Constraints:        15639
Variables:          64772
Integers:           60170
Nonzeros:           189714
Density:            0.019 %


SOLUTION RESULT

  MIP: Time limit exceeded, integer solution exists


    MIN Cost            =          127358



MACROS


    Macro Name                             Values
  -----------------------------------------------
    Dist                                     1994
    Util                              0.763376932
```

DECISION VARIABLES

VARIABLE X[i,LT,j,AT IN Xidx,TType] :

i	LT	j	AT	TType	Activity	Reduced Cost
1	5	6	7	4	1	2475
1	6	18	8	5	1	1350
1	10	2	11	1	1	336
1	11	21	13	5	1	2025
1	11	22	13	1	1	1064
1	12	4	13	1	1	504
1	12	13	14	4	1	2175
1	12	13	14	5	1	2175
1	13	7	15	1	1	504
1	13	12	15	1	1	840
1	13	23	14	1	1	280
1	13	29	15	1	1	896
1	14	18	16	1	1	1008
1	14	21	16	1	1	1512
1	14	28	16	1	1	1792
1	15	8	17	2	1	1575
1	15	20	17	4	1	1800
1	15	25	17	1	1	728
1	16	24	18	1	1	1512
1	17	2	18	1	1	336
1	17	3	20	1	1	2352
1	17	4	18	1	1	504
1	17	17	19	1	1	1456
1	18	15	20	5	1	1650
1	19	12	21	1	1	840
1	19	13	21	4	1	2175
1	19	21	21	1	1	1512
1	20	8	22	1	1	1176
1	20	22	22	2	1	1425
1	20	29	22	1	1	896
1	21	10	23	5	1	2025
1	22	2	23	1	1	336
1	23	7	25	1	1	504
1	23	28	25	4	1	2400
2	11	11	13	1	1	2016
2	18	26	20	1	1	1624
2	23	18	24	1	1	672
2	25	1	26	1	1	336
3	20	1	23	1	1	2352
4	13	1	14	1	1	504
4	18	1	19	1	1	504
5	18	1	21	1	1	2128

5	22	1	25	5	1	2850
6	7	1	9	4	1	2475
6	17	1	19	1	1	1848
6	22	1	24	1	1	1848
7	15	1	17	1	1	504
7	25	23	26	1	1	616
8	17	19	19	2	1	2400
8	22	1	24	1	1	1176
9	19	1	22	4	1	3225
9	24	1	27	2	1	3225
10	22	1	24	4	1	2025
10	23	20	24	5	1	525
11	13	1	16	1	1	2352
12	15	1	17	1	1	840
12	21	1	23	1	1	840
13	14	1	16	4	1	2175
13	14	1	16	5	1	2175
13	21	10	22	4	1	525
14	20	1	24	1	1	3528
14	22	1	26	1	1	3528
15	20	5	22	5	1	1425
17	19	27	21	1	1	1288
18	8	1	10	5	1	1350
18	16	26	18	1	1	1064
18	24	2	25	1	1	672
19	19	25	21	2	1	2700
20	17	9	19	4	1	2025
20	24	1	26	5	1	1800
21	13	1	15	5	1	2025
21	16	6	17	1	1	728
21	21	6	22	1	1	728
22	13	1	15	1	1	1064
22	22	9	24	2	1	2175
23	14	1	15	1	1	280
23	26	1	27	1	1	280
24	18	1	20	1	1	1512
25	17	1	19	1	1	728
25	21	1	23	2	1	975
25	27	1	29	4	1	975
26	18	14	20	1	1	1848
26	20	14	22	1	1	1848
27	21	1	24	1	1	2464
28	16	5	18	1	1	1008
28	25	25	27	4	1	1650
29	15	1	17	1	1	896
29	22	1	24	1	1	896

VARIABLE Y[i,LT,j,AT,PType,PDest IN Yidx] :

i	LT	j	AT	PType	PDest	Activity	Reduced Cost

1	5	6	7	3	6	1	0.0000
1	6	18	8	3	18	1	0.0000
1	10	2	11	2	2	1	0.0000
1	10	2	11	2	11	1	0.0000
1	11	21	13	3	21	1	0.0000
1	11	22	13	2	22	1	0.0000
1	12	4	13	2	4	1	0.0000
1	12	13	14	2	13	1	0.0000
1	12	13	14	3	13	1	0.0000
1	13	7	15	2	7	1	0.0000
1	13	12	15	2	12	1	0.0000
1	13	23	14	2	23	1	0.0000
1	13	29	15	2	29	1	0.0000
1	14	18	16	2	14	1	0.0000
1	14	18	16	2	18	1	0.0000
1	14	21	16	2	6	1	0.0000
1	14	21	16	2	21	1	0.0000
1	14	28	16	2	5	1	0.0000
1	14	28	16	2	28	1	0.0000
1	15	8	17	2	8	1	0.0000
1	15	8	17	2	19	1	0.0000
1	15	20	17	2	9	1	0.0000
1	15	20	17	2	20	1	0.0000
1	15	25	17	2	25	1	0.0000
1	16	24	18	1	24	1	0.0000
1	16	24	18	2	24	1	0.0000
1	17	2	18	1	14	1	0.0000
1	17	2	18	1	26	1	0.0000
1	17	2	18	2	26	1	0.0000
1	17	3	20	1	3	1	0.0000
1	17	3	20	2	3	1	0.0000
1	17	4	18	1	4	1	0.0000
1	17	17	19	1	17	1	0.0000
1	17	17	19	2	17	1	0.0000
1	17	17	19	2	27	1	0.0000
1	18	15	20	1	5	1	0.0000
1	18	15	20	1	15	1	0.0000
1	18	15	20	2	15	1	0.0000
1	19	12	21	1	12	1	0.0000
1	19	13	21	1	13	1	0.0000
1	19	13	21	2	10	1	0.0000
1	19	21	21	1	6	1	0.0000
1	19	21	21	1	21	1	0.0000
1	20	8	22	1	8	1	0.0000
1	20	22	22	1	9	1	0.0000
1	20	22	22	1	22	1	0.0000
1	20	29	22	1	29	1	0.0000
1	21	10	23	1	10	1	0.0000
1	21	10	23	1	20	1	0.0000
1	22	2	23	1	2	1	0.0000
1	22	2	23	1	18	1	0.0000
1	23	7	25	1	7	1	0.0000
1	23	7	25	1	23	1	0.0000
1	23	28	25	1	25	1	0.0000

1	23	28	25	1	28	1	0.0000
2	11	11	13	2	11	1	0.0000
2	18	26	20	1	14	1	0.0000
2	18	26	20	1	26	1	0.0000
2	18	26	20	2	26	1	0.0000
2	23	18	24	1	18	1	0.0000
7	25	23	26	1	23	1	0.0000
8	17	19	19	2	19	1	0.0000
10	23	20	24	1	20	1	0.0000
13	21	10	22	2	10	1	0.0000
15	20	5	22	1	5	1	0.0000
17	19	27	21	2	27	1	0.0000
18	16	26	18	2	14	1	0.0000
20	17	9	19	2	9	1	0.0000
21	16	6	17	2	6	1	0.0000
21	21	6	22	1	6	1	0.0000
22	22	9	24	1	9	1	0.0000
26	18	14	20	2	14	1	0.0000
26	20	14	22	1	14	1	0.0000
28	16	5	18	2	5	1	0.0000
28	25	25	27	1	25	1	0.0000

Appendix G: WPCD Scheduling Tool User Manual

WCPD_Sched_Tool_User_Manual.docx