Ram Wireless Optimization Project: Enhancing Regional Office Efficiency

Executive Summary:

Ram Wireless, a retail service provider with stores across Virginia, tasked us with optimizing the assignment of stores to four key regional offices—Staunton, Warrenton, Richmond, and Tappahannock. The project aimed to minimize travel costs while ensuring workload feasibility, addressing inefficiencies caused by excessive travel times and imbalanced office capacities. This study was conducted as part of the INFO 645 Prescriptive Analytics course at Virginia Commonwealth University, combining optimization modeling and data-driven decision-making.

The problem involved assigning stores to regional offices while considering constraints such as employee travel times, regional office capacity, and activity-specific workloads. We utilized a combination of Python, AMPL, and Excel Solver to analyze data and implement optimization models. Travel costs were based on a mileage rate of \$0.585 per mile and a salary rate of \$26 per hour, with data sourced from operational records in "realignment_data_new.xlsx."

The analysis was conducted in three stages. First, stores were assigned to the nearest regional office based solely on mileage, resulting in a total travel cost of **\$192,040.16**. However, this approach led to imbalanced workloads, making the solution infeasible. Next, we incorporated workload feasibility constraints into the optimization model, which increased the total cost to **\$195,479.31** but produced a feasible and balanced solution. Finally, we refined the assignments to address geographical inconsistencies, reducing the total cost to **\$194,130.69**. This adjustment, while cost-effective, resulted in a minor feasibility issue for Warrenton's Merchandising workload, exceeding capacity by 98.38 hours.

In conclusion, we recommend retaining the refined solution with adjustments to redistribute workloads or hire additional staff for Warrenton. This strategy ensures cost-efficient operations, balanced workloads, and improved travel efficiencies, addressing both operational and geographical challenges effectively.

Problem Statements:

Ram Wireless, a retail service provider with stores distributed across Virginia, relies on regional offices to deliver critical operational support, including inventory management, payroll processing, hiring, marketing, and merchandising. The company's current store-to-regional office assignments, developed incrementally over time, have led to significant inefficiencies, including:

- Excessive Travel Costs: Employees spend substantial time commuting between regional offices and stores, increasing operational expenses related to mileage and salary costs.
- Workload Imbalances: Some regional offices are overburdened, while others have underutilized resources, reducing overall productivity and employee satisfaction.
- Geographical Inconsistencies: Store assignments do not always align with logical proximity to regional offices, further exacerbating inefficiencies.

Data Overview

Input Data:

- **Store Information**: Annual service hours required by each store, categorized by activity.
- **Travel Data**: Distances and times between stores and regional offices, with infeasible assignments replaced by high penalties.

- **Regional Office Capacities**: Available annual hours for each activity at each regional office.

Cost Parameters:

- **Mileage Rate**: $0.585 per mile (vehicle fuel and wear).
- **Salary Rate**: $26 per hour (employee travel time).

Let,

R = {Staunton, Richmond, Warrenton, Tappahannock} be the set of regional offices.

S = {Albemarle County, Amherst County, Augusta County, Buckingham County, Caroline County, Charles City County, Chesterfield County, City of Fredericksburg, City of Richmond, Culpeper County, Cumberland County, Dinwiddie County, Essex County, Fauquier County, Fluvanna County, Goochland County, Greene County, Hanover County, Henrico County, Hopewell County, James City County, King and Queen County, King George County, King William County, Louisa County, Madison County, Mathews County, Nelson County, New Kent County, Orange County, Page County, Powhatan County, Prince George County, Prince William County, Rappahannock County, Rockbridge County, Rockingham County, Shenandoah County, Spotsylvania County, Stafford County, Warren County, Westmoreland County, York County} be the set of the stores.

A = {Inventory, Payroll, Hiring, Marketing, Merchandising} be the set of support areas (activities).

$mileage_{ij} = The\ distance\ in\ miles\ from\ store_j\ to\ regional\ office_i, for\ i \in R\ and\ j \in S$

$time_{ij} = the\ travel\ time\ in\ hours\ from\ store_j\ to\ regional\ office_i, for\ i \in R\ and\ j \in S$

$mileage\_rate\ = 0.585\ (given\ average\ cost\ per\ mille)$

$hourly\_rate\ = 26\ (average\ employee\ hourly\ rate)$

$hours\_avail_{ik} = Annual\ hours\ available\ for\ activity_k\ at\ regional\ office_i\ for\ k \in A\ and\ i \in R$

$hours\_requ_{jk} = Annual\ hours\ required\ for\ activity_k\ at\ store_j\ for\ k \in A\ and\ j \in S$

$mileage\_cost_{ij} = Mileage\ cost\ between\ regional\ office_i\ and\ store_j, for\ j \in S\ and\ i \in R$

$$= mileage_{ij} * mileage\_rate\ , for\ j \in S\ and\ i \in R$$

$salary\_cost_{ij} = Salary\ cost\ per\ trip\ between\ reginal\ office_i\ and\ store_j, for\ j \in S\ and\ i \in R$

$$= time_{ij} * hourly\_rate\ , for\ j \in S\ and\ i \in R$$

$trips_{jk} = Number\ of\ annual\ trips\ required\ for\ each\ activity_k\ at\ store_j, for\ j \in S\ and\ k \in A$

$Tota\_travel\_cost\ = The\ overall\ travel\ cost.$

Objective in words:

Decide how to assign each store to a regional office so that the total travel cost, which includes mileage and salary costs associated with all required trips for activities is minimized, subject to the following constraints:

- Each store is assigned to exactly one regional office.
- For each activity, the total hours required to perform the activity at all assigned stores, combined with the travel time needed for trips to these stores, must not exceed the available working hours allocated for that activity at the regional office.
- The assignment of a store to a regional office is either made (1) or not made (0).

Decision Variables:

The model determines whether a store is assigned to a specific regional office. For example, if a store is assigned to an office, the variable representing that assignment is set to 1. If not, it is set to 0.

Let

x_{ij} $= Is\ a\ binary\ variable\ indicating\ whether\ store_j\ is\ assigned\ to\ office_i, for\ j \in S\ and\ i \in R$

$$x_{ij} \in \{0,1\}, \quad j \in S\ and\ i \in R$$

Algebraic Formulation:

Objective

$$Min \sum_{j \in S} \sum_{i \in R} \sum_{k \in A} trips_{jk} \,.\, (2.\, mileage\_cost_{ij} \ + 2.\, salary\_cost_{ij}) \,.\, x_{ij}$$

The primary goal of the model is to minimize the total costs associated with assigning stores to regional offices.

Travel Costs: This is the cost of traveling back and forth (a round trip) between a regional office and a store. It depends on the distance between the store and the office (mileage) and the number of trips needed.

Employee Time Costs: This is the cost of the time employees spend traveling between the office and the store. It also includes round trips and depends on how many trips are required annually for specific tasks.

For every possible store-to-office assignment, the model calculates the combined travel and operational costs. It then identifies the set of assignments that results in the lowest total cost.

Constraints

Assignment Constraint

$$s.t. \quad \sum_{i \in R} x_{ij} = 1, \qquad j \in S$$

Every store must be assigned to exactly one regional office. This means that no store is left unassigned, and no store is assigned to more than one office. This ensures that there is a clear and exclusive responsibility for each store.

Feasibility Constraint

$$\sum_{j \in S} \left(hours\_requ_{jk} + 2.time_{ij}\,.trips_{jk}\right).x_{ij} \leq hours\_avail_{ik}, i \in R \text{ } and \text{ } k \in A$$

The feasibility constraint ensures that each regional office can handle the total workload from all its assigned stores without exceeding the time available for specific activities. The workload includes:

Activity Time at Stores: Regional office employees perform activities like inventory checks, merchandising, and payroll tasks. The time required depends on the type of task and the store's needs.

Travel Time: Travel includes round trips (to and from the store). For each store-office assignment, the time for one round trip is calculated.

Annual Trips: Stores require multiple visits per year for each activity. For example, 50 annual trips for merchandising and 20 for payroll. The total travel time is multiplied by the number of trips for each activity

Combined Workload: The total workload for an office is the sum of:

- Activity time for all assigned stores.
- Travel time, scaled by annual trips.

This combined workload is compared against the office's available hours to ensure capacity is not exceeded.

Binary Constraint

$$x_{ij} \in \{0,1\} \;\; i \in R \; and \; j \in S$$

The model ensures that every store is either assigned to a specific office or not assigned at all. There is no partial assignment or sharing of responsibility between offices.

Assumptions:

- Mileage and salary rates are consistent across all offices and stores.
- The number of trips required for each activity at a store is predetermined and stable.
- Each store is assigned to only one regional office.
- Regional offices have fixed available hours, and these cannot be exceeded.
- Travel times are constant and unaffected by factors like traffic.
- All inputs (e.g., distances, workloads, and capacities) are accurate and known.
- Some stores cannot be served by certain regional offices due to predefined constraints.
- It is assumed that regional offices collectively have enough capacity to meet all workloads.

Implementation

An implementation and solution of the model using Python, AMPL, and CBC is available here:

https://colab.research.google.com/drive/1CrTEdgiVqxyg2fV-COF3QgF9sIZPpUv3?usp=sharing

Modeling Methodology and Results

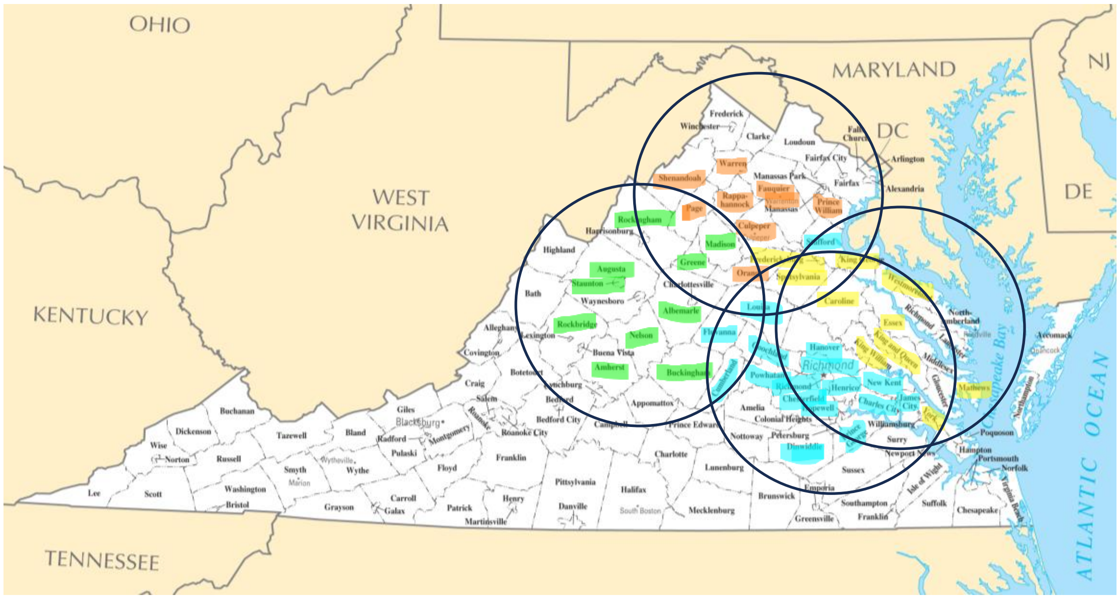
To solve the problem of assigning stores to regional offices efficiently, we applied mathematical optimization techniques using binary integer programming. The optimization model aimed to minimize total travel costs while ensuring that workloads assigned to each regional office did not exceed its available capacity. This required a careful balance between cost efficiency and operational feasibility.

The data preparation phase involved consolidating critical inputs, including travel distances and times between stores and regional offices, regional office capacities for various activities, and the workload requirements of each store. Infeasible assignments, such as those marked as “–” in the data, were replaced with high penalty values (10000) to ensure they were avoided during the optimization process. This step ensured that the model would generate only realistic and feasible assignments.

The optimization model was implemented using Python and AMPLpy, a library that integrates seamlessly with optimization solvers. The CBC solver was chosen for its ability to handle large-scale binary integer programming problems efficiently. Google Colab was used to facilitate collaborative coding and data analysis, while Excel Solver was used in the initial stages for feasibility testing and smaller-scale evaluations. Together, these tools enabled a robust and scalable approach to solving the assignment problem.

The initial solution minimized costs by assigning stores to their nearest regional offices based solely on mileage. This resulted in a total travel cost of $192,040.16. However, the solution proved infeasible as it did not account for workload constraints, with some regional offices exceeding their available capacity for certain activities. This highlighted the need to incorporate operational feasibility into the model.

To address these limitations, we refined the model by adding constraints to ensure that no regional office was overburdened. The updated model considered both cost efficiency and workload feasibility, assigning stores to regional offices while ensuring that the total hours required for all activities, including travel time, remained within each office’s available capacity. This feasibility-constrained solution increased the total cost to $195,479.31 but provided a practical and balanced allocation of resources.



During this phase, we observed that Stafford County was initially assigned to Richmond. However, upon reviewing the geographical alignment on the map, it became apparent that Stafford County was much closer to Warrenton and would be more appropriately assigned to that regional office. This geographical discrepancy prompted a reassignment of Stafford County from Richmond to Warrenton. This adjustment, along with minor reallocations to address workload balance, resulted in a slight increase in total cost to $195,561.08. While this improved geographical alignment, other inconsistencies, such as Rappahannock County being assigned to Staunton instead of Warrenton, remained.

To refine the solution further, we implemented a targeted reassignment that retained the original assignments but focused exclusively on reassigning Stafford County from Richmond to Warrenton. This adjustment resulted in a reduced total cost of $194,130.69, demonstrating improved cost efficiency and better geographical alignment. However, this reassignment caused Warrenton's Merchandising workload to exceed its available hours by 98.38 hours, creating a new feasibility challenge.

This is the outcome of the optimal allocation performed:

Stores	Staunton	Warrenton	Richmond	Tappahannock
Albemarle_County	1	0	0	0
Amherst_County	1	0	0	0
Augusta_County	1	0	0	0
Buckingham_County	1	0	0	0
Caroline_County	0	0	0	1
Charles_City_County	0	0	1	0
Chesterfield_County	0	0	1	0
City_of_Fredericksburg	0	0	0	1
City_of_Richmond	0	0	1	0
Culpeper_County	0	1	0	0
Cumberland_County	0	0	1	0
Dinwiddie_County	0	0	1	0
Essex_County	0	0	0	1
Fauquier_County	0	1	0	0
Fluvanna_County	0	0	1	0
Goochland_County	0	0	1	0
Greene_County	1	0	0	0
Hanover_County	0	0	1	0
Henrico_County	0	0	1	0
Hopewell_County	0	0	1	0
James_City_County	0	0	1	0
King_George_County	0	0	0	1
King_William_County	0	0	0	1

Stores	Staunton	Warrenton	Richmond	Tappahannock
King_and_Queen_County	0	0	0	1
Louisa_County	0	0	1	0
Madison_County	1	0	0	0
Mathews_County	0	0	0	1
Nelson_County	1	0	0	0
New_Kent_County	0	0	1	0
Orange_County	0	1	0	0
Page_County	0	1	0	0
Powhatan_County	0	0	1	0
Prince_George_County	0	0	1	0
Prince_William_County	0	1	0	0
Rappahannock_County	0	1	0	0
Rockbridge_County	1	0	0	0
Rockingham_County	1	0	0	0
Shenandoah_County	0	1	0	0
Spotsylvania_County	0	0	0	1
Stafford_County	0	0	1	0
Warren_County	0	1	0	0
Westmoreland_County	0	0	0	1
York_County	0	0	0	1

Conclusion And Recommendations:

The Office Realignment Project minimized travel costs while balancing workloads effectively. The initial cost of $192,040.16 was infeasible due to workload imbalances. A feasible solution was achieved at $195,479.31 by incorporating capacity constraints. Refinements reduced costs to $194,130.69 but created a minor workload imbalance at Warrenton's Merchandising capacity.

Recommendations:

Redistribute Workloads:

To address Warrenton's Merchandising workload violation, surplus capacity from other regional offices should be shifted to Warrenton. Offices with significant unused capacity can support this redistribution.

Hire Additional Staff:

If workload redistribution is not feasible, hiring additional staff at Warrenton is recommended to meet the excess workload demands.

Periodic Reviews:

Conduct regular assessments of store assignments to adapt to evolving conditions, such as changes in workloads, travel distances, or operational constraints. This ensures the model remains relevant and effective in addressing new challenges.

Appendix:

Generative AI Interaction

AI was used to clarify optimization concepts, assist with narrative explanations, and refine the results, conclusions, and recommendations. It provided insights into objective functions, constraints, and results interpretation while ensuring clear and concise formatting of the report.

For a detailed explanation of how the document was generated through AI coaching, refer to the transcript at the following link:

https://chatgpt.com/share/671e6117-af54-8006-9841-d70976075480

https://chatgpt.com/share/674cdf1b-90c4-8006-9cb1-96dfd7ae66c4

https://chatgpt.com/share/67515422-bfb8-800f-8cba-afb51eb08ebb

https://chatgpt.com/share/6751548e-18f0-8006-bff0-4a3e8a17492e