RESEARCH & DEVELOPMENT

NCDMV Optimal Location Analysis

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16. Abstract

Growing population and changing demographics in North Carolina result in increased demand for DMV services specifically for REAL ID issuance. Considering the geographic distribution and the spatial characteristics of the demand, decision makers need to open new locations or reallocate limited resources among existing DMV offices to reduce wait times and improve operational efficiency. In this study, we performed a location analysis and developed a set of analytical tools that can be integrated as “NCDMV Next-Generation Organizational Intelligence Platform”. The proposed technology would ensure that all DMV offices operate at targeted efficiency and have adequate service capacity to provide maximum service quality to NCDOT customers.

Focusing on operational performance and the strategic priorities, the research team developed a new performance management framework considering four competitive dimensions (sustainability, efficiency, and effectiveness, responsiveness, flexibility) and four perspectives (customers, operations, finance, employees). After analyzing statewide performance dashboard (SAS Scorecard) data and demand projections, a resource reallocation optimization model is developed and solved to identify the best capacity expansion option while keeping the expansion costs and efforts at minimum. The optimization solution indicates specific offices that should receive additional resources and from which location it should be reallocated. Additionally, locations that should have extra labor hours and mobile unit support are indicated. For instance, the North Raleigh office should receive two DLEs from Franklin and two DLEs from Roxboro with four extended hours allocated for an optimal solution. Another example would be Durham East, which would utilize two DLEs from Aberdeen and three DLEs from Cary and a weekend labor allocation of four additional hours. For in-depth analysis of operational efficiency, a simulation model with 3D animation is created for the North Raleigh Driver License Office. Based on the baseline simulation results, it would take 215 days to satisfy the projected REAL ID demand of 2,813,167. If the improvement of information technology infrastructure is complemented with an additional greeter, 2.8 million customers can be served within 90 days.

The suggested Next-Generation Organizational Intelligence Platform consisting of state-of-the-art business intelligence and data analytics tools, including SAS Scorecard, ArcGIS, resource reallocation optimization, and simulation, would enhance the operational performance of the NCDMV and provide a more customer-centric approach.

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NCDMV OPTIMAL LOCATION ANALYSIS

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North Carolina's REAL ID

FAYETTEVILLE STATE UNIVERSITY

Table of Contents

List of Tables

List of Figures

List of Acronyms

AHP: Analytical Hierarchy Process

DLE: Driver License Examiner

DLO: Driver License Office

DMV: Division of Motor Vehicles

NCDMV: North Carolina Division of Motor Vehicles

NCDOT: North Carolina Department of Transportation

PII: Personally Identifiable Information

MCDM: Multi Criteria Decision Making

Executive Summary

Growing population and changing demographics in North Carolina result in increased demand for DMV services specifically for REAL ID issuance. Considering the geographic distribution and the spatial characteristics of the demand, decision makers need to open new locations or reallocate limited resources among existing DMV offices to reduce wait times and improve operational efficiency. In this study, we performed a location analysis and developed a set of analytical tools that can be integrated as "NCDMV Next-Generation Organizational Intelligence Platform". The proposed technology would ensure that all DMV offices operate at targeted efficiency and have adequate service capacity to provide maximum service quality to NCDOT customers.

Overall, the results suggested Bahama in Durham County as the best location to open a new DMV office, followed by Gibsonville in Guilford County and Black Mountain in Buncombe County. Prior to opening new DMV facilities, which would incur very high cost on the State budget, we recommend NCDMV consider other capacity expansion options such as overtime and overstaffing at the existing locations until the Federal REAL ID deadline, and increasing DMVs' operational performance. The preliminary results of efficiency analysis indicated that 50 facilities have extra capacity to cover the excess demand faced by an overflowing 29 facilities. Focusing on operational performance and the strategic priorities, the research team developed a new performance management framework considering four competitive dimensions (sustainability, efficiency, and effectiveness, responsiveness, flexibility) and four perspectives (customers, operations, finance, employees).

After analyzing statewide performance dashboard (SAS Scorecard) data and demand projections, a resource reallocation optimization model is developed and solved to identify the best capacity expansion option while keeping the expansion costs and efforts at minimum. The optimization solution indicates specific offices that should receive additional resources and from which location it should be reallocated. Additionally, locations that should have extra labor hours and mobile unit support are indicated. For instance, the North Raleigh office should receive two DLEs from Franklin and two DLEs from Roxboro with four extended hours allocated for an optimal solution. Another example would be Durham East, which would utilize two DLEs from Aberdeen and three DLEs from Cary and a weekend labor allocation of four additional hours. For in-depth analysis of operational efficiency, a simulation model with 3D animation is created for the North Raleigh Driver License Office. Based on the baseline simulation results, it would take 215 days to satisfy the projected REAL ID demand of 2,813,167. If the improvement of information technology infrastructure is complemented with an additional greeter, 2.8 million customers can be served within 90 days.

The suggested Next-Generation Organizational Intelligence Platform consisting of state-of-the-art business intelligence and data analytics tools, including SAS Scorecard, ArcGIS, resource reallocation optimization, and simulation, would enhance the operational performance of the NCDMV and provide a more customer-centric approach.

1. Introduction

Growing population and changing demographics in North Carolina have resulted in increased demand for transportation services. Improving tax-payers' ability to utilize the transportation network of the state through the creative application of powerful technologies has been the focus of the North Carolina Department of Transportation (NCDOT). The NC Transportation Innovation Council (NC-TIC) is concerned with fostering an organizational culture of collaboration that identifies and implements meaningful innovations to deliver efficient solutions to the public with modern and high-quality deliverables. Rapid implementation of technology, tactics, and techniques regarding transportation programs and all levels of state government is a primary goal of NC-TIC (NC-TIC, 2020).

The North Carolina Division of Motor Vehicles (NCDMV) administers and enforces laws regulating the operation of vehicles or the use of highways; and issues commercial and personal drivers' licenses, registers vehicles, and suspends or revokes drivers' licenses. The NCDMV's mission is "to deliver quality customer support through professional driver and motor vehicle services while promoting highway safety and protecting accurate and secure information.[1]" The reinforcement of the Federal REAL ID Act, which requires a REAL ID, US passport or another federally approved identification to board commercial flights and enter secure federal buildings, is posing a challenge to NCDMV to adhere to the federal requirements by satisfying the demand for NC REAL ID in all parts of the state including urban and rural areas. In 2018, NCDMV initiated a collaboration with Fayetteville State University to locate enough site locations to handle the increased workload by October 2020. This project provides analysis tools for decision-makers to assess the need to open new locations, or to reallocate the existing resources among existing DMV locations for improved operational efficiency and customer experience.

Measuring and evaluating the operational efficiency of existing DMV facilities requires analytic techniques that rely on mathematical programming and simulation. In this project, an integrated framework is developed to ensure that all DMV offices operate at targeted performance levels and have adequate service capacity to provide maximum service quality to NCDOT customers. Specifically, GIS-based data mining and optimization model to allocate available excess capacity to locations with insufficient capacity have been developed. The project outcome provides an implementable solution that will balance the workload between high-volume and low-volume driver license offices.

1.1. Background

The NCDMV has 114 driver license offices and 130 privately operated license plate agencies and registration offices to serve the state's 10.5 million residents (2019 Census Data). As of 2019, the state of North Carolina is among the top eight states with 7.6 million licensed drivers that own or operate 9.3 million registered vehicles. With the third-highest migration rate of 7.9% (the difference of in-migration and outmigration per 1,000 residents), the North Carolina population is increasing by 334 every day or 2,342 people every week, which increases the demand for DMV services. However, geographic distribution and the spatial characteristics of the population poses additional challenges for efficient allocation of resources. Figure 1 presents the population changes between 2010 and 2017.

[1] https://www.nc.gov/agency/motor-vehicles-division

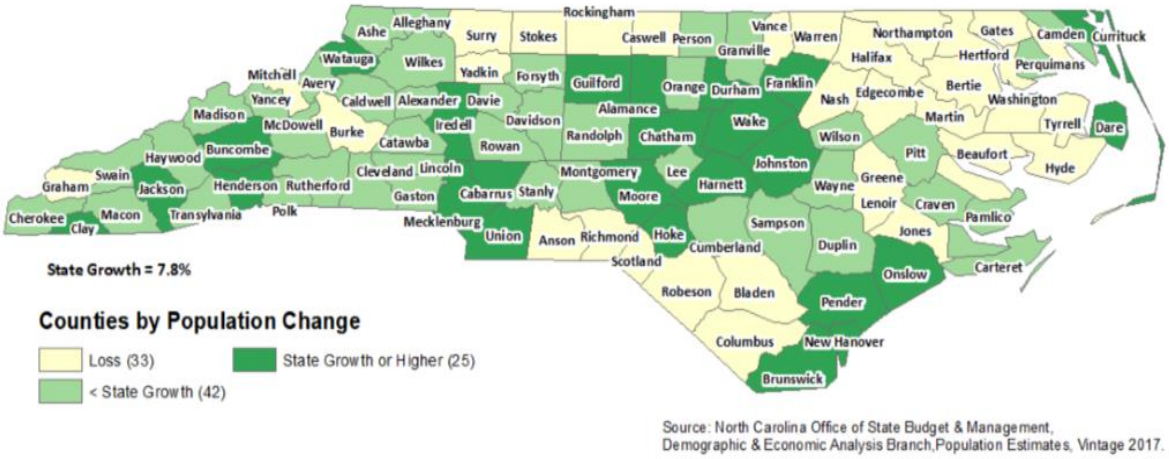


Figure 1. Percentage Population Change in North Carolina Counties, April 1, 2010-July 1, 2017

The North Carolina Department of Transportation (NCDOT) is concerned about a very steep demand regarding REAL ID issuance in relation to the rapidly approaching Federally mandated deadline of October 2020. REAL ID is a form of identification that is validated by specially trained Driver License Examiners after the presentation of supporting documentation such as birth certification, Social Security card, marriage certificate, etc. in person at the DMV offices during normal business hours. The REAL ID (Gold Star) may be applied to any of the NC credentials below if requested by the applicant with the appropriate REAL ID qualifying documents, i.e., birth certificate, U.S. Passport, Social Security Card, marriage certificate (if applicable) and two forms of proof of residency (physical address); as well as any other document requirements relative to the specific NC credential of interest, i.e., proof of insurance for a driver license. Due to the surge in REAL ID demand, NCDMV constantly evaluates demand for its services and may offer extended hours (7-5 pm), and/or Saturday hours (8-12 pm) as needed. Note that the first REAL ID issuance is not an online transaction and requires an in-person application.

1.2. State of the Art, Science, and Practice

In our current study, we developed an integrated approach for selecting the optimal NCDMV driver license locations using expert knowledge, data mining, Analytic Hierarchy Process (AHP), Geographical Information System (GIS), and Maximal Covering Location Problem (MCLP). The previous approach (Figure 5) identifies the two-level location criteria through experts' input as part of the AHP process, yielding demographic attributes, flexibility, efficiency, cost, and access to public facilities. Following the weight assessment for all criteria and sub-criteria, normalized weights are used for location suitability analysis in ArcGIS. Based on our projections for the demand and related geospatial data, alternative DMV locations are determined and visualized through ArcGIS. Finally, the alternative locations are evaluated by AHP weights, and the multicriteria location selection problem is optimized to maximize the coverage across the state.

In alignment with NCDOT's mission and goals, the broad impact of this project will be greater customer service and effective and efficient use of DMV facilities.

Short term impacts of the project will be:

- improving customer service by alleviating the long-waiting lines and insufficient capacity to meet the demand for REAL ID.
- optimizing capacity expansion decisions

- allocating mobile capacity to high-demand locations
- ensuring efficient use of limited resources and accountability

Long term-impacts (after REAL ID issue is over)

- provision of necessary service capacity in anticipation of positive or negative population growth in different areas
- adoption of potential future changes in the service characteristics such as offering online driver license services, issuing drone licenses, or other future services

The main output of the project is the "**NCDMV Next-Generation Organizational Intelligence Platform**," which is an integrated, real-time business analytics module with four components: A new SAS Scorecard System with web and ArcGIS connectivity to share real-time wait time statistics with the public; an optimization and simulation component; a SAS-based optimization model that maximizes the efficiency and minimizes the total effort to optimally allocate the operational capacity of the existing DMV facilities; and an ArcGIS map with SAS-link displaying live metrics from an organizational intelligence perspective. Each component provides an implementable solution that will balance the workload among all DLOs. The proposed methodology would optionally be integrated with NCDOT's analytics system for periodic use.

1.3. Purpose and Scope

The overall objective of this study is to conduct location analysis for potential new DMV facilities and analyze the resource reallocation potential to improve the efficiency of the existing Driver License Offices (DLOs). The specific objectives are as follows:

1. Forecast demand for REAL ID and assess the true service capacity of the selected DLOs
2. Determine capacity gaps and thresholds to achieve the target efficiency level
3. Develop a GIS and simulation-based optimization model to allocate available excess capacity to locations with insufficient capacity
4. Make recommendations regarding the opening of new DMV offices

The motivation of this research effort is the reduction of increased costs associated with new facility creation by utilizing existing resources and personnel to address a steep demand by the October 2020 date that was rapidly approaching. NC DMV had no accurate measure of the quantity of people that would potentially require REAL ID, which tied into not being able to accurately forecast daily demand levels, but also posed a real problem when it came to measuring their performance-to-date. In order to accurately measure these core and critical metrics, an accurate analysis had to be performed to assess the real demand that existed in the state.

This approach was critical because it not only reduced the amount of tax-payer money spent, but it was also a more rapid response than the creation of new facilities. Preliminary location analysis revealed that suggested alternative locations for new DMV offices were already within proximity to existing REAL ID issuance service areas. Small adjustments, such as adding an additional employee to assist with the documentation verification, were shown to vastly improve the speed of service for customers throughout an entire day of operations. This led to the conclusion that a deeper evaluation of the existing format of license offices could potentially yield greater gains. Furthermore, there was already a system in place for requesting additional personnel from other facilities. What NC DMV lacked was a way to strategically assess where personnel should be shifted in anticipation of demand, to be more proactive and less reactive, and a cost-effective method for analyzing various office layouts and strategies.

The over-arching goal was to create a variety of useful assessment and analysis tools for NCDMV so that they may address forecasted fluctuations in demand with agility. These tools would include a GIS model of service areas combined with population densities that could be linked with SAS via NCDMV's IT department, an algebraic optimization model for aggregate planning, and a 3D simulation that would allow for low-cost evaluation of various operational designs in a license issuing office.

One of the initial challenges was to obtain relevant data for exploration that could potentially yield meaningful insights to address the problem of severely high demand. This goal transformed into how to obtain data without the assistance of NC DMV. There simply was not a proper system in place for the reasonable delivery of data in a timely manner. This challenge was overcome by using publicly available census data to analyze demand. This was performed with ArcGIS software with datasets that included major and minor road networks and current office locations' latitude and longitude.

1.4. Research Approach

The first step of this project includes location analysis to locate potential new locations for Driver License Offices (DLOs) to be opened. For location analysis, expert knowledge, and a multicriteria decision-making approach is utilized. The next step was demand forecasting using spatial network analysis in ArcGIS. Given the demand projections, the following step is the analysis of the operational characteristics (working hours, number of customers served, number of workstations, number of driver license examiners, process rates, etc.) and performance metrics of the NC DMV Driver License Offices. The project team developed a streamlined performance management framework for NCDMV in line with the DOT REPORT program. Analysis of the current capacity and productivity measures for each existing facility and capacity gap is assessed, and DLOs are classified as high volume or low volume. Based on the capacity cap assessment, a mixed-integer network optimization model was constructed to select the best capacity expansion option(s) for facilities with insufficient capacity while keeping the expansion and reallocation costs and efforts to a minimum. Note that capacity expansion options may include technology investments, personnel reallocation, transfer of mobile units, adding new physical locations, or overtime. Finally, a discrete-event simulation model with 3D animation is developed to assess the impact of the potential changes not limited to suggested optimal reallocations solutions.

Specific research tasks include:

- Determine data requirements and data availability
- Data collection and processing
- Demand forecasting and analysis of service area coverage
- Mathematical programming to optimize resource reallocation
- Simulation modeling

1.5 Organization of the Report

This report is organized as follows. The next section reviews the literature followed by location analysis to determine alternative locations for the new DMV facilities, specifically, Driver License Offices. Section 4 covers demand forecasting by service area network analysis. Section 5 discusses technology, workforce, and space-related limitations while comparing the operational performance of DLOs and presents a new performance management framework for NCDMV. Section 6 covers the optimal resource reallocation model, followed by the simulation model presented in Section 7.

The project team's recommendations, including the "NCDMV Next-Gen Organizational Intelligence Platform," COVID-19 implications, and future work, are presented in Section 8. The Implementation and Technology Transfer Plan presented in section 9 concludes the report.

2. Literature Review

One of the oldest problems facing organizations in marketing and operations management is where to locate organizations (Stevenson, Hojati, and Cao 2007). The location decision is strategic with long term impact on an organization's capacity to serve its market and maximize benefits to the organization. Although globalization and emerging technologies, such as online transactions, change the way location decisions are made by many organizations, these factors have made location decisions even more important for service organizations, including NCDOT. A typical location decision involves identifying the market to be served by the facility, searching for potential locations, and then selecting the best site.

From the earliest research (Hoover 1937; Czamanski 1981), location relative to customers has been identified as the central decision for many industries, including retailing (Reynolds and Wood 2010). Methods and technologies for doing so have become increasingly sophisticated and are essential to today's largest retailers as they select locations (Hernández and Bennison 2000). While most studies on location decisions are theoretical with a major focus on cost factors, Karakaya and Canel (1998) provide empirical evidence to determine the importance of various location-related variables for different industries (manufacturing, retail, banking, insurance, and consulting) and for different company sizes. Even small and moderately sized retail firms are often familiar with basic location techniques and are increasingly using geographic information systems (GIS) to support their decision-making, although they may not be able to afford the more sophisticated methods such as neural networks and expert systems (Reynolds and Wood 2010). The most advanced location analysis techniques are usually employed by high-tech, energy and manufacturing industries with an emphasis on the forward facility location problem (Clark and Rowley 1995; Ghadge, Yang, Caldwell, Koenig and Tiware 2016; Seyedhosseini, Makui, Shahangaghi and Torkestani 2016; Torkestani, Seyedhosseini, Makui and Shahanaghi 2016).

Typical focus on customer demographics and specific applications of facility location problems are studied by Clarke and Rowley, 1995; Clarke et al. 2003; Ghosh and McLafferty, 1987; Laulajainen, R., & Stafford, H., 1995. The literature on location analysis of nonprofits and government facilities remains an open area (Sirinesa and Shnoer, 2018). A study by Walton, Wallace, & Martin (2015) explores the requirements for REAL ID by presenting the eight REAL ID requirements, recommendations for implementation, personally identifiable information (PII) security, training requirements, and review of compliant states and their methods. A more recent article by Martin et al. (2018) presents a nationwide comparative study of DMV service operations with a focus on improvements in productivity and service quality. The authors used a mixed-methods approach, including surveys and Data Envelopment Analysis, which resulted in best practices and the highest efficiency achieved by DMV offices in Minnesota, Texas, Indiana, and Ohio.

To gain an understanding of potential optimization models that could assist with responding to demand, an article covering D-level nested logit models with random utility and maximization equivalent to elimination by aspects was reviewed (Li, Rusmevichientong, and Topaloglu, 2014). Additional articles reviewed included: 1. Another study by Sumida et al. (2016) generates candidate assortments that guarantee the inclusion of optimal solutions to balance cost and utility in an assortment optimization setting under the multinomial logit model. 2. Capacity Constrained Assortment Optimization under the Markov Chain based Choice Model, which utilized an assortment optimization model that leverages the Markov Chain based choice model and "local-ratio" paradigm to allow the transformation of non-linear function into a linear function (Goyal, Segev, & Ye, 2015). 3. Near-Optimal Algorithms for the Assortment Planning Problem under Dynamic Substitution and Stochastic Demand, an efficient algorithm with a near-optimal performance that guarantees for assortment planning problems, useful for optimizing assortments of services, equipment, and personnel (Goyal & Segev, 2016). Ultimately the optimization models reviewed were overly complex based on the aggregate planning that needed to be addressed. However, they were highly informative and assisted with understanding the dynamics of a service planning problem.

In recent years, NCDOT has made great strides in improving the tax-payer ability to utilize the transportation network of North Carolina through the creative application of powerful technologies. Recent efforts have been initiated to invest in resources for sustainable transportation, and a commission has been formed to offer recommendations for the modernization of transportation revenues (NCDOT FIRST Commission, 2019). The NC Transportation Innovation Council (NC-TIC) is concerned with fostering an organizational culture of collaboration that identifies and implements meaningful innovations to deliver efficient solutions to the public with modern and high-quality deliverables. Rapid implementation of technology, tactics, and techniques with regard to transportation programs and all levels of state government is a primary goal of NC-TIC (NC-TIC, 2020). This is in alignment with the goal of this research, which is to utilize existing resources instead of wasting time, money, and resources that would inherently be in opposition to environmental sustainability.

In a joint effort with NCDOT and JMP, lean six sigma, data analysis, and Monte Carlo simulation methods are used to improve customer experience by minimizing wait times, which was reported to be more than 30 minutes (JMP Customer Story, 2017). The team used JMP software to determine the potential causes for excessive wait times and identify which causes were most significant. Simio was used to develop the simulation model to determine optimum staffing. The results suggested that an additional 13 examiners at the high-volume driver license offices were optimal.

According to 2017-2018 NCDOT customer service survey results (Findley et al., 2018), 38% of 2,300+ respondents reported that they visited a Driver License Office in the past year. The top five most important factors that influenced which DMV office North Carolinians chose to visit are reported to be the location (86% of the respondents); shorter wait times (25%); previous experience (20%); the attitude of employees/customer service (15%) and hours of operation (11%).

All these studies and NCDOT documentation helped the project team to better execute the primary goals of the project. Instead of only providing a general idea of the knowledge landscape, it provided crucial elements in the pursuit to reduce wait times and increase REAL ID issuance.

3. Location Analysis

In this section, we present the results of Expert Knowledge and Evidence-Based Location Methodology (Appendix Figure 1), developed by Glackin and Adivar (2019). This framework structures the location decision by combining current business model search techniques with underlying lean startup methods and an overall analytical framework for location analysis. We implement the Factor Rating Method (FRM) as a multicriteria decision-making (MCDM) tool which uses multiple location factors and their weights to evaluate alternative locations. AHP is applied to calculate weights for sixteen key factors that emerged from the third iteration of the NVDMV's Business Model Canvas. The AHP method developed by Saaty (1994) helps with determining factor weights by assigning a score to each factor or criteria according to the decision-makers pairwise comparisons with the other factor or criteria.

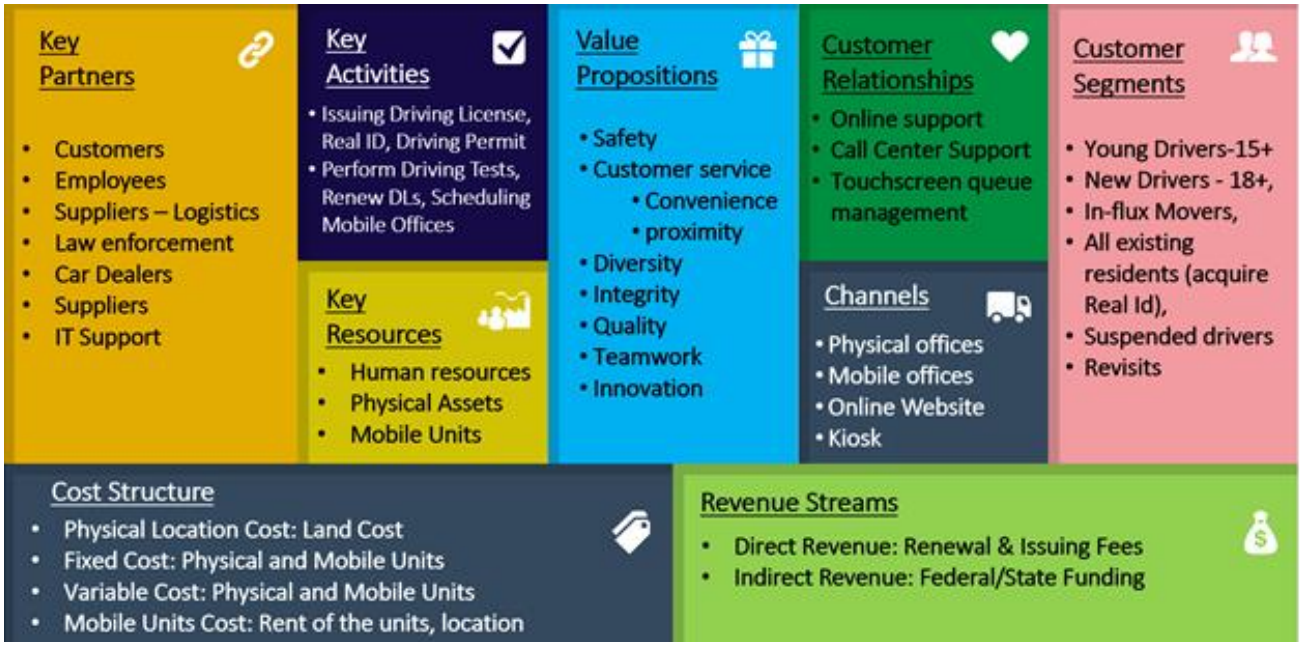


Figure 2. NCDMV's Business Model Canvas

Business Model Framework requires understanding the business model of the NCDMV, which was critical in determining the correct criteria for the location selection decision. Therefore, the Business Model Canvas for NCDMV was created, and iteratively changed over several weeks. The canvas, presented in Figure2, identifies the key factors involved in creating and capturing value to provide value through contributions of proceeds to the mission-driven activities of the affiliate. The business model canvas suggested population density, cost, sustainability, land availability/ownership flexibility, and convenience as the most important location criteria to be considered in the analytical framework.

Analytical Framework consists of a 7-step algorithm that includes data analytics, analytical hierarchy process, and factor rating method.

Step 1. Identification of quantifiable location criteria
Step 2. Using pairwise comparison matrices to calculate AHP weights
Step 3. Determining alternative locations
Step 4. Data mining for scoring
Step 5. Processing and standardizing data
Step 6. Factor rating method to determine total weighted scores
Step 7. Ranking for selecting the best location(s)

Using SAS 9.4 and ArcGIS software, all seven steps are executed to determine alternative DMV locations based on current and required geographic coverage. NCDMV's Business Model Canvas and literature review suggested using sixteen location criteria (C1 to C16) to quantify population density, cost, sustainability, land availability/ownership flexibility, and convenience. After forming a 16x16 square matrix of factors identified in Step 2, we asked experts to make the judgment of the dominance of one factor over another factor based on the AHP preference scale presented in Appendix-Table 1. An example comparison matrix is shown in Appendix-Figure 2. Once all the AHP preference values were assigned, weights for the location criteria were obtained. Overall, the most important criteria were found to be C1 – population density (14.55%), C13 – proximity to shopping malls (14.28%), and C16 – proximity to highways (11.77%). The location criteria and the corresponding AHP weights that have been used in the remainder of the study are presented in Table 1.

Table 1. Location Criteria and the AHP Weights

Index	**Location Criteria**	**Weight**
C1	Population density of the county (15+)	0.1455
C2	Cost of living	0.0556
C3	Housing rent	0.0303
C4	Housing value	0.0154
C5	County overall tax rates (sales)	0.0128
C6	All transit performance score	0.0732
C7	Natural disaster index	0.0179
C8	Unemployment	0.0259
C9	Recent job growth (over the past year)	0.0681
C10	Future job growth (over the next 10 years)	0.0760
C11	Clean energy index	0.0117
C12	Number of companies with 500+ employees (2011)	0.0595
C13	Proximity to shopping malls	0.1428
C14	Proximity to hospitals	0.0536
C15	Proximity to universities	0.0939
C16	Proximity to highways	0.1177

To determine the alternative locations for the new DMV facilities, suitability and service coverage analysis was performed using AHP weights obtained in Step 2. We used the geo-coordinates and shapefiles to create the layers indicating population density and proximity to highway exits, hospitals, shopping centers, and universities in ArcGIS (Appendix Figure-3). The Figure 3 below displays the integrated output raster wherein dark color spots represent the most suitable area for opening the new offices, and the ranges from "light brown" to "green spots" represent the least suitable area based on the population density and proximity to highway exits, hospitals, shopping centers.

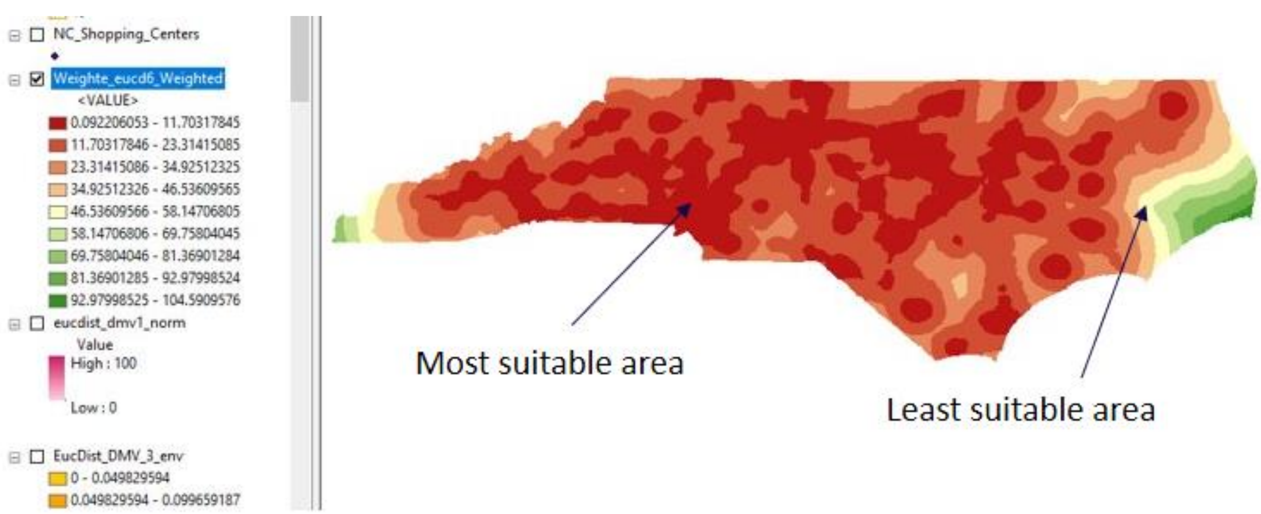


Figure 3. Results of the Suitability Analysis

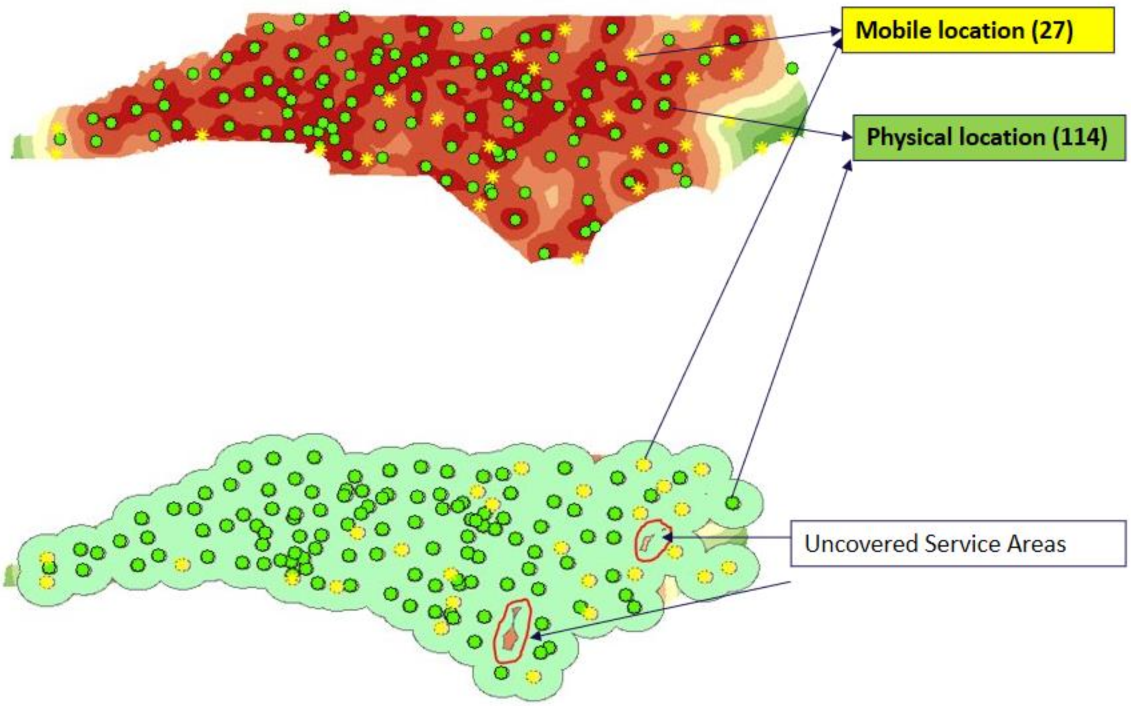


Figure 4. Service Area Coverage with 20-mile Radius from the Existing Locations

Service coverage analysis with a 20-mile radius (light green circles around yellow and green dots, created using Euclidean distance) from the existing 114 physical and 27 mobile DMV locations are displayed in Figure 4. The two areas marked as uncovered service areas are unhabituated military areas; therefore, neglected. Contrary to the DMV's assumption of lack of coverage, our service coverage analysis in ArcGIS resulted in full coverage across the state, which eliminates the consideration of uncovered service areas as the candidate locations for the new facilities.

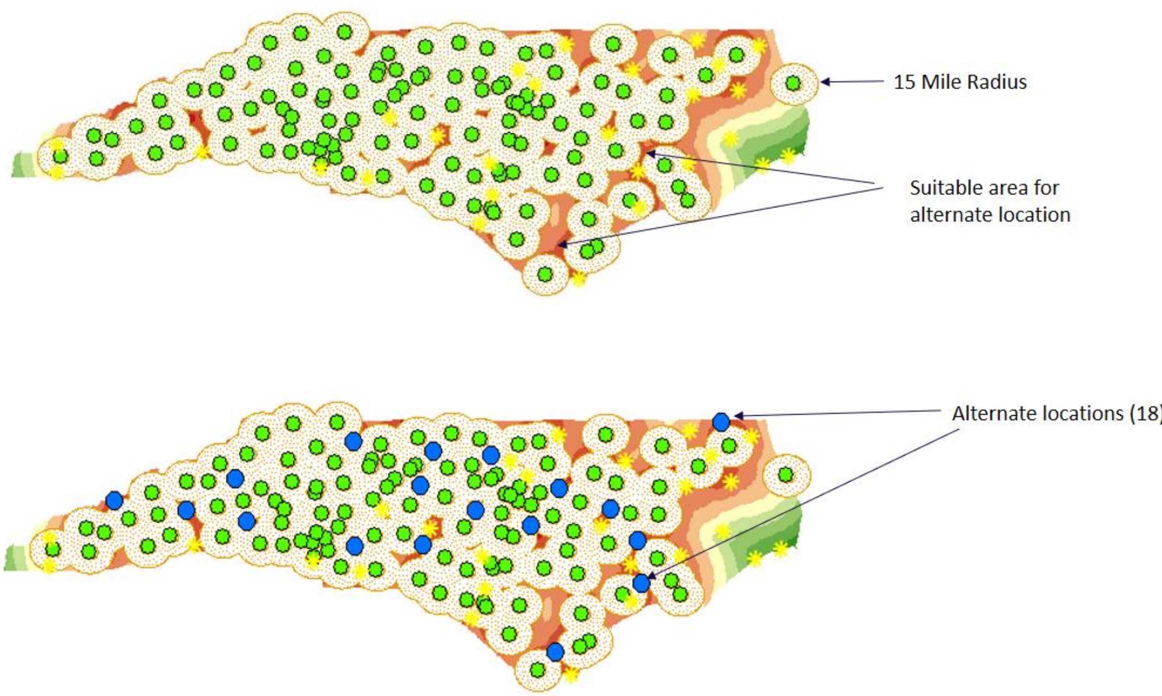


Figure 5. 18 Alternative Locations with a 15-mile Radius

After simulating various radius values for the service area coverage analysis in ArcGIS, the project team observed that the 15-mile proximity in Euclidean distance offers more convenience for the customers and delivers the best results for finding new locations. Service area coverage analysis with a 15-mile radius resulted in 18 areas that are not covered, therefore constituting alternative locations to open new DMV driver license offices. Figure 5 displays visualization through ArcGIS, in which the new alternative locations (blue dots) overlaid with a 15-mile service area around the existing locations. Note that "yellow asterisks" represent current mobile locations (27), and green dots represent the existing DMV offices (114).

Table 2. Alternative Locations as Potential Sites for the New DMV Offices

S. No.	*County*	*Location*	*Ranking*
1	Jackson	Cherokee	15
2	Buncombe	Black Mountain	3
3	Cleveland	Casar	12
4	Caldwell	Collettsville	13
5	Stokes	Pinnacle	11
6	Stanly	Locust	9
7	Randolph/Guilford	Climax	7
8	Chatham	Moncure	4
9	Nash	Middlesex	14
10	Pitt	Farmville	8
11	Brunswick	Leland	6
12	Craven	Vanceboro	16
13	Camden	South Mills	18
14	Jones	Maysville	17
15	Durham	Bahama	1
16	Moore	Jackson Springs	10
17	Johnston	Four Oaks	5
18	Guilford	Gibsonville	2

The map coordinates of the eighteen alternate locations are used to list the potential new locations (Table 2) for the next step, which involves data mining for scoring each alternative location with respect to sixteen location criteria. The data sources for the scores in Table 3 are listed in the Appendix. After gathering raw score data from various sources for all the factors or criteria, normalized data and the AHP weights have been used to identify the ranking of the alternative locations.

The factor rating method was implemented to compute the total score for each alternative location across multiple location criteria. Overall, the results suggested Bahama in Durham County as the best location to open a new DMV office, followed by Gibsonville in Guilford County and Black Mountain in Buncombe County. Note that the ranking of the alternative locations (Table 2) indicates strong association with the population estimate and economic analysis by the Office of State Budget and Management, which can be considered as a validation of the results. Prior to opening new DMV facilities, which would take longer than the available time (again, an October 2020 REAL ID deadline) and incur very high cost on the State budget, we recommend NCDMV consider other capacity expansion options such as overtime and overstaffing at the existing locations until 2020, and increasing DMVs' operational performance.

Table 3. Raw Scores for Alternative Locations

Criteria	Cherokee	Black Mountain	Casar	Collettsville	Pinnacle	Locust	Climax	Moncure	Middlesex	Farmville	Leland	Vanceboro	South Mills	Maysville	Bahama	Jackson Springs	Four Oaks	Gibsonville
Population Density of the County (15+)	22	323	171	144	86	126	148	83	142	221	125	118	35	17	858	111	184	651
Cost of Living	84.6	114.3	80.5	84.1	91.4	87.2	86.8	117.2	87.9	87.7	107.2	87.2	106	83.1	102.4	99.5	96.7	89.1
Housing Rent (Ave County)	1151	1546	893	905	1081	1114	951	1467	883	1032	1311	1013	1363	886	1372	1080	1201	1074
Housing value	145600	288600	99300	108100	156900	143200	136700	295800	136800	121000	248300	146200	252300	106200	234600	225400	179500	150400
County Overall Tax Rates (sales)	6.8	7	6.8	6.8	6.8	6.8	7	6.8	6.8	7	6.8	6.8	6.8	6.9	7.5	6.8	6.8	6.8
All Transit Performance Score - mass transit infrastructure (county)	0	1.9	0	0	0.1	0	0.2	0.1	1	1.3	0.3	0.4	0	0	4.2	0.1	0.1	2.7
Natural Disaster Index	13	14	16	14	13	15	13	13	14	15	15	16	15	14	16	13	14	16
Unemployment	4.4	3	4	3.8	3.6	3.6	3.7	3.3	5.2	4.3	5.2	4.2	3.8	4.2	3.5	3.9	3.6	4.1
Recent Job Growth (over past Year)	0.8	1.6	1.4	1.6	1.6	1.6	1.3	2	-1.1	1.1	2.7	0.4	-0.3	0	2	2.3	2.9	1.4
Future Job Growth (Over next 10 years)	35.7	40.9	37	37.5	32.4	37.6	31.7	41.8	21.2	32	42.8	29.8	29.4	33.5	42.5	40.3	46.3	32.1
Clean energy index - Capacity (MW) (County)	305.09	16.97	83.38	26.77	4.23	78.37	23.57	38.59	151.99	30.39	118.88	104.21	5.02	25.26	25.18	33.26	189.92	29.23
Number of Companies with 500+ Employees (2011)	24	497	187	132	57	113	208	98	263	333	121	201	4	18	671	179	281	969
Proximity (#) to Shopping Malls	0	3	1	1	1	4	5	3	1	1	2	1	0	2	4	0	1	4
Proximity to Hospitals	4	8	6	8	8	3	5	2	2	2	3	2	2	4	9	5	2	4
Proximity to Universities	0	4	2	1	0	2	1	0	1	2	1	1	0	0	3	1	1	7
Proximity to Highways	4	0	0	0	6	0	4	10	8	7	0	0	0	0	0	6	6	3

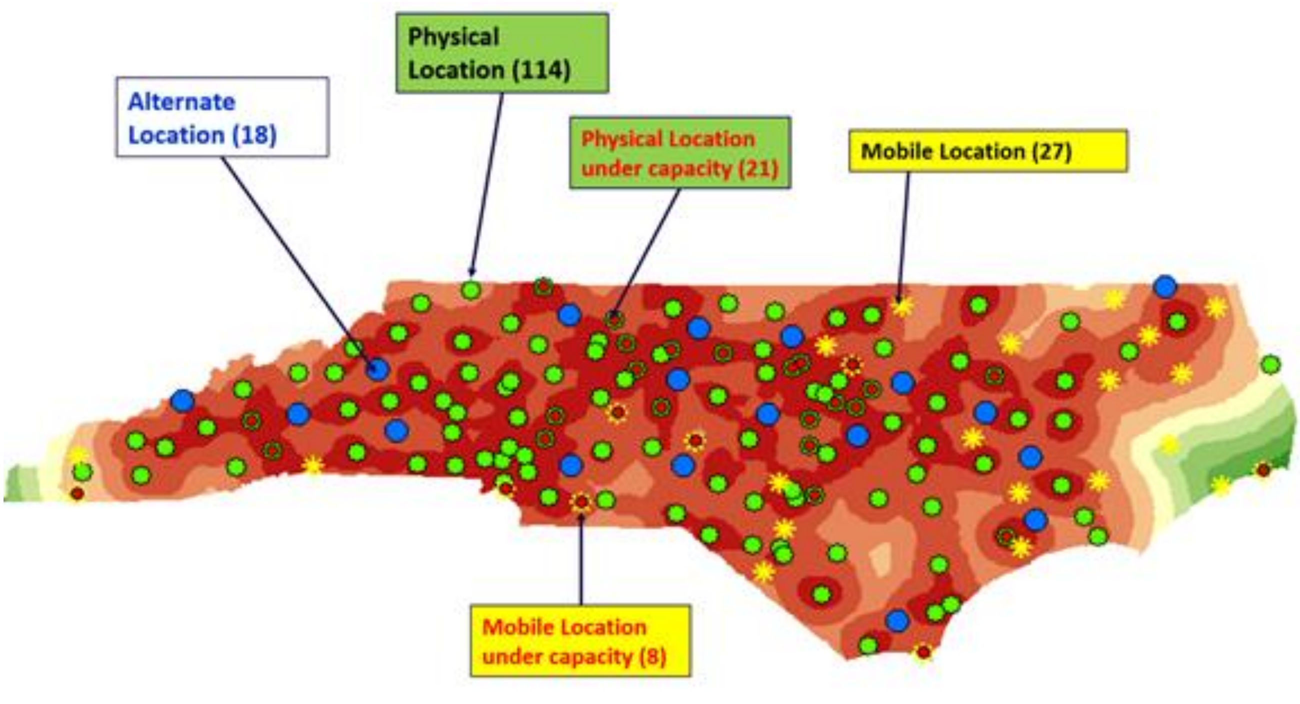


Figure 6. Existing Locations and Efficiency Analysis by ArcGIS

For this purpose, we analyzed the efficiency of the existing locations by comparing the workload (demand) and the service capacity (supply) of the individual facilities. Assuming that a workstation at a DMV office can serve 50 REAL ID customers in an 8-hour day, and 80% of the county population over age 15 makes up the demand, we categorized each facility as a starving or overflowing facility. Under these assumptions, we identified 29 locations (20.5% of the total) as overflowing, meaning inadequate capacity and unable to serve the projected demand. Similarly, 50 facilities (35% of the total) are categorized as starving or having excess capacity. Facility categorizations are overlaid with the alternative locations and presented in Figure 5, where "green circles" represent current starving facilities; "yellow asterisks" represent current mobile locations with no excess demand; "blue circles" represent the alternate locations (18); "dark red dots" with a green border are the current physical locations which are overflowing (21); and "red dots with yellow border" are the overflowing mobile locations which are under capacity.

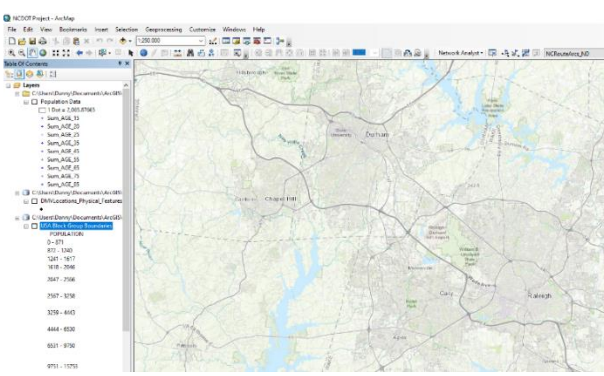
The preliminary results of efficiency analysis indicated that 50 facilities have extra capacity to cover the excess demand faced by the overflowing 29 facilities. Thus, our recommendation and the next step is to focus on operational performance and to conduct in-depth efficiency analysis using business analytics tools such as forecasting, simulation, and optimization.

4. Forecasting REAL ID Demand by Service Area Network Analysis

The NCDOT has been facing a high demand for REAL ID that results in long waiting times at license office locations and concerns about customer satisfaction. Until March 2020, the consensus about meeting the previous Federal deadline of October 2020 was that NCDMV could not meet the demand with the existing capacity of the license issuing offices. However, at the time, the organization had no accurate assessment of the demand remaining to be satisfied. Identification of the existing demand was critical, not only at the state level but also disaggregated at the county and individual DMV office level. Detailed data was not available from the organization; therefore, the project team resorted to data mining and forecasting methods utilizing publicly available census data. The issue remained: How to separate aggregate statewide census data and transform it into REAL ID demand that was localized by the individual office?

To extract the population data that was relevant to the NCDMV, a platform that could identify the demand for each office was required. Each REAL ID issuing office had to be plotted via latitude and longitude, and the surrounding population needed to be assigned in reasonable segments to each office. Considering NCDOT's value proposition for convenience and the service coverage requirements of the NCDMV, the most viable solution was to use GIS technology, specifically ESRI ArcGIS (McCoy and Johnston, 2005). ArcGIS is a Geographic Information System (GIS) designed to work with data-rich maps and geographic information maintained by the Environmental Systems Research Institute (ESRI). GIS technology is an important tool for transportation (Thill, 2000) and many other industries (see http://www.esri.com/industries.html) to analyze and visualize spatial data to explore relationships, patterns, and trends. Spatial queries, map overlay, proximity calculations, buffer analysis, geostatistical techniques, raster analysis, network analytics, and space-time dynamics are the most common tools for spatial analysis (Mitchell, 1999). ArcGIS has multiple options for modeling spatial relationships. These options include Euclidean distance, inverse distance, fixed distance, Delaunay triangulation, travel time, and travel distance based on a real road network. The Euclidean distance was the option used to conduct the location analysis presented in the previous section. Since the traffic conditions or the physical landscape can dramatically change, the actual driving time and distance use of the actual travel times - rather than Euclidean distances- for more accurate results was selected.

In this section, it is described how various demographic datasets embedded in ArcGIS are used to layer different map file types and hybridize them into insightful visualizations and perform network analyses. Typical population census data is at the aggregate level and lacks the geographic definition required to create a service area network in ArcGIS, which requires defined borders. The research revealed the availability of census block data. US census block data contains (Figure 7. b) polygonal segments that disaggregate country-wide data into specific geographic areas, allowing analysts to derive insight from specific latitudes and longitudes.



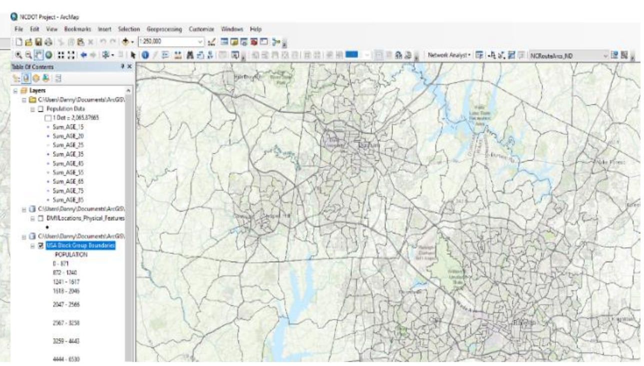


Figure 7. (a) Plain Topographical Map (b) After Census Block Data Implementation

Each grey-lined polygon represents a geographic segment of data. Each segment contains demographic data pertaining to age, income, etc. The next steps involved plotting offices to create service area coverage with the network analyst tools in ArcGIS and extraction of those polygonal census data that would yield insight for potential demand that each office was facing. To extract the population data that was relevant to the NCDMV, each office's latitude and longitude need to be added as a layer to the existing map. Location and attribute data for 114 DMV facilities in North

Carolina were acquired by geocoding addresses in ArcGIS and converting to point features. This allows for the calculation of specific areas that were within certain driving times of each office, assuming most customers will drive to their nearest office. Average driving speed of 35 mph was used to emulate the speed most drivers will achieve on average in a typical trip, including a combination of unimpeded travel, traffic, and traffic stops.

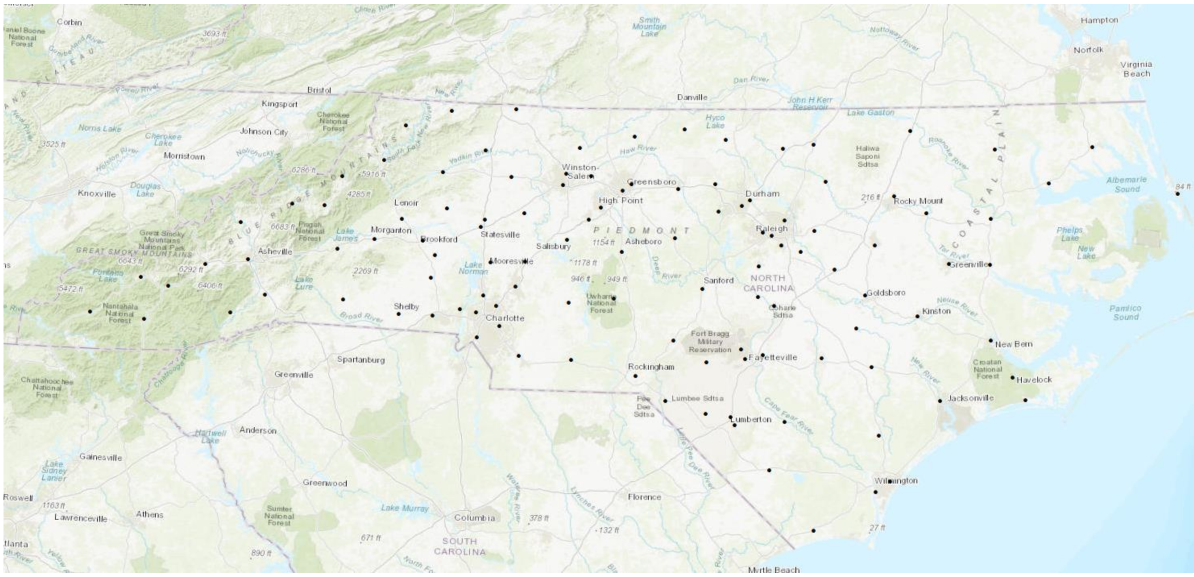


Figure 8. Map with DMV Driver License Office Locations

Each black dot represents a DMV license issuing office capable of providing REAL ID service to a customer. These plotted points are the central locations that were utilized in the network analysis. Furthermore, a map containing the major and minor road networks of North Carolina was implemented in the existing layers. Travel time is modeled as a function of distance and travel speed. This map layer was used to calculate driving distances, and which census block polygon could be reached within a predefined amount of time: 15-, 20-, or 30-minute coverage areas.

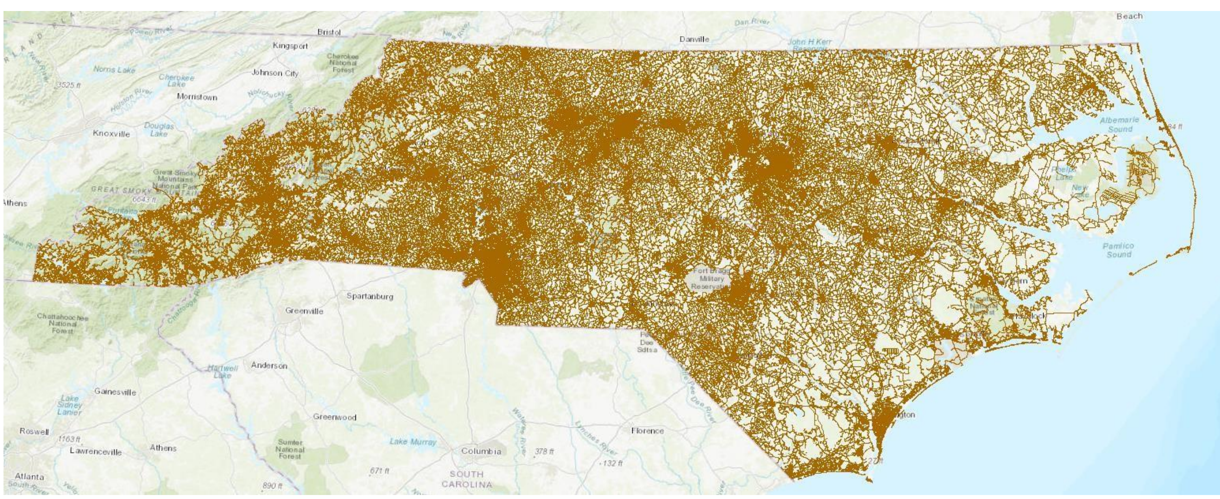


Figure 9. Major and Minor Road Networks

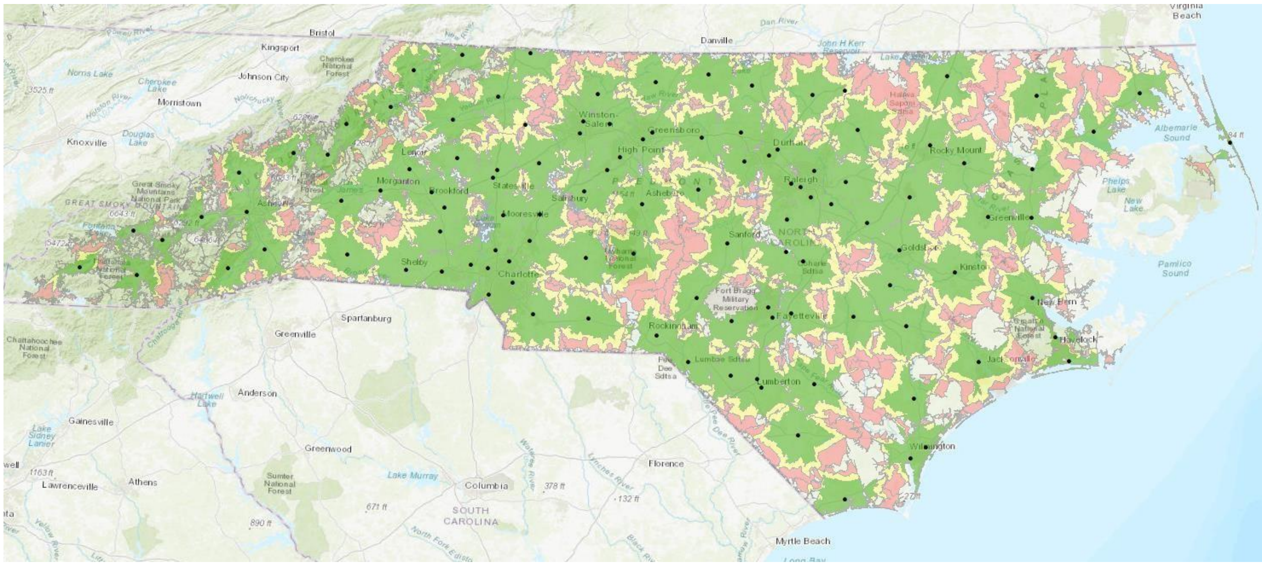


Figure 10. Service Area Network within 15-20-30-minute Travel Time

All major and minor roads were incorporated in the map and combined with office locations to create a network service area that could be blended with the census block data to extract an accurate assessment of the demand each office faced. As Figure 10 illustrates, the service coverage area identified by actual travel times, as well as Euclidean distance methods, share similar maps resulting in a general agreement that existing DMV locations provide almost full coverage throughout the state. The 15-min coverage area was 15,840 square miles, comprising 29.4% of the total area identified for the state (53,819 mi^2). The 20-min coverage area was 33,472 mi^2, comprising 62.2% of the total area identified for the state. The 30-min coverage area was 47,417 km2, comprising 88.1% of the total area identified for the state of North Carolina. With the existing 114 locations, NCDMV provides 30-min-accessible service to 7.6 million drivers in North Carolina (Table 4).

Table 4. Service Area Network Statistics

Travel Time	Driver Population	Number of Households	Area Coverage (mi^2)	% NC Area
0 to 15 min	2,172,777	1,050,495	15,840	29.4%
15 to 20 min	1,941,751	940,302	17,632	32.8%
20-30 min	3,439,795	1,685,910	13,945	25.9%
Total	7,554,324	3,676,707	47,417	88.1%

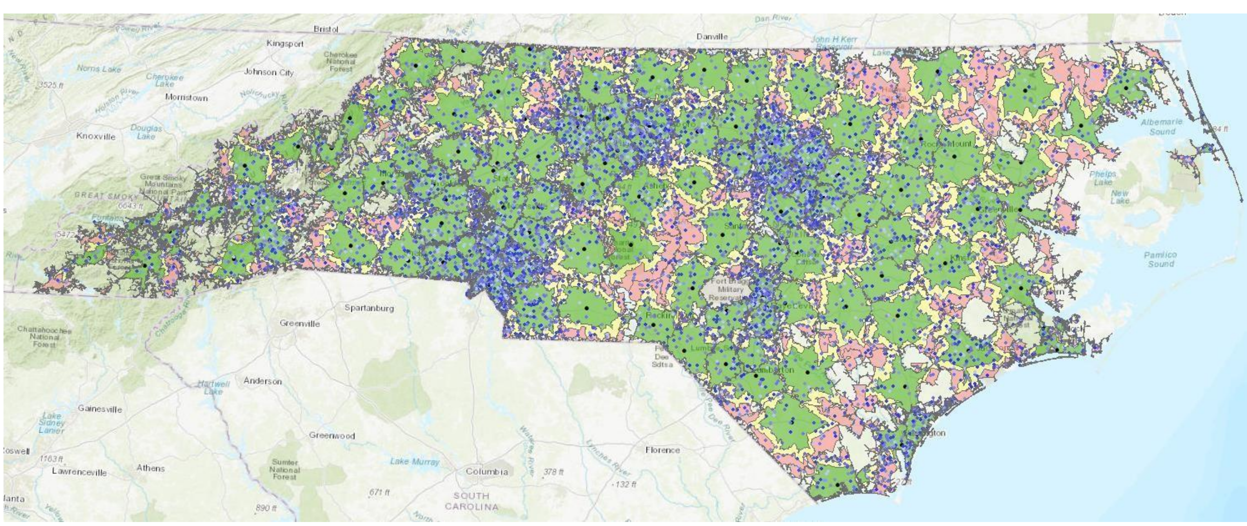


Figure 11. Population Density and Service Coverage Overlay

Each office now had a 15-minute (green), 20-minute (yellow), and 30-minute (red) service area that was constructed using the census block polygonal data segments. Population data comprised of census block data containing only ages 15 to 85 were layered as a blue dot density visualization. Ages over 85 and under 15 were not considered due to low or non-existent probability of demand for REAL ID. Service area network analysis provides a highly valuable visualization that rapidly identifies those offices faced with steep demand and those that were being underutilized and could be used as support for those offices with high demand. Additional variables factored into the demand projections include educational attainment (61% with college experience or degrees) and percentage of North Carolinians who do not have a passport (65%). It is assumed that 60% of the eligible population will obtain a REAL ID.

ArcGIS has the capability of exporting data sets, including service area networks, in the format of a *.csv (Comma Separated Values) file. This data set contained disaggregated census data that was filtered for those eligible to obtain a REAL ID and assigned to office locations nearest their record of address. Data in this format is compatible with SAS JMP Pro 14 software, a flexible platform that is well designed for analyzing and visualizing datasets. The ArcGIS service area network data export table in the Appendix illustrates characteristics of various service areas and quantities of people in each age category. A critical detail worth noting is the more than adequate service area coverage that the existing license issuing offices already provides. The creation of additional license issuing offices is unneeded and costly.

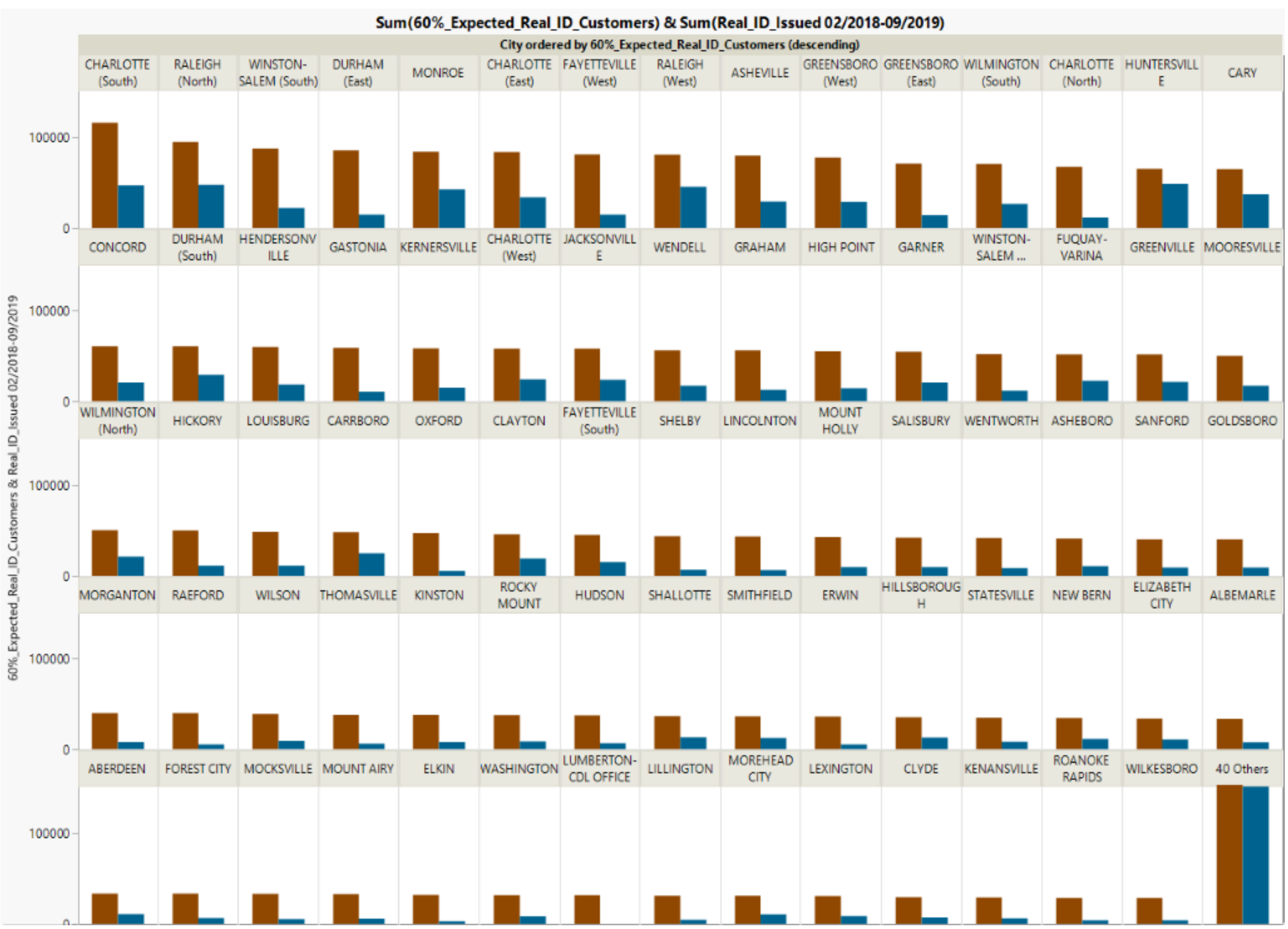


Figure 12. Expected REAL ID Demand vs. REAL IDs Issued

Figure 12 presents a visualization of the NCDMV's rate of issuance compared to the projected demand for REAL ID, assuming 60% of the current drivers demand by the population. The blue columns of the bar graph represent NCDMV's total REAL IDs issued as of September 2019, while the red columns represent only a 60% demand of REAL ID. The possibility for the REAL ID demand to be a higher percentage is a highly probable issue facing NCDMV; what is needed is a flexible tool for rapid response to spikes in demand that was approximately ten times higher than what had already been issued over a similar span of time. NCDMV has completed approximately 1.7 million REAL ID transactions to date. Proposals have been put forth to expand the number of driver license issuing facilities, which appear to be a misguided use of resources considering adequate service area coverage. There are many facilities which are not being used at full capacity or have low traffic. By implementing the proposed organizational intelligence platform that hosts multiple business analytics tools, NCDMV can satisfy the REAL ID demand without opening new facilities. This requires a technological investment to incorporate what is suggested with the current SAS powered data management system.

5. Comparative Performance and the Proposed Performance Management Framework

The overall objective of this project was to minimize the number of new locations to be opened by the efficient use of existing resources. NCDMV administration prioritizes minimizing waiting times at high-demand locations and leveraging capacity utilization across all locations - including rural areas. For this purpose, the project team performed multiple interviews, process analysis and reviewed the relevant literature to gain more insights about the customers' perceptions towards NCDMV services. A recent study on customer service survey (Findley et al. 2018) indicates high satisfaction with the courtesy and helpfulness of DMV staff. However, most of the survey respondents selected length of wait time at DMV offices (73%) as the issue that needs the most attention, followed by the overall quality of customer service at DMV office (51%) and convenience of hours of operation at DMV office (45%).

The project team reached consensus that from an operational perspective, NCDMV is experiencing long wait times and customer service challenges due to a set of:

- Technology related limitations
- Workforce related limitations
- Space-related limitations (number of terminals)
- Lack of integrated performance management framework.

This section will shed some light on these limitations with the anticipation that NCDMV would take necessary actions to eliminate them. Without waiting times and other performance measures related to efficiency, the project team used demand projections and observations to select specific driver license offices to conduct efficiency analysis. For this purpose, the following metrics are calculated to identify Driver License Offices (DLOs) that need operational improvements:

- Expected net demand = Projected demand – total number of REAL IDs issued so far
- Capacity utilization = total number of REAL IDs issued / service capacity to issue REAL ID
- Number of days required to fulfill the net demand = Net demand / daily service capacity

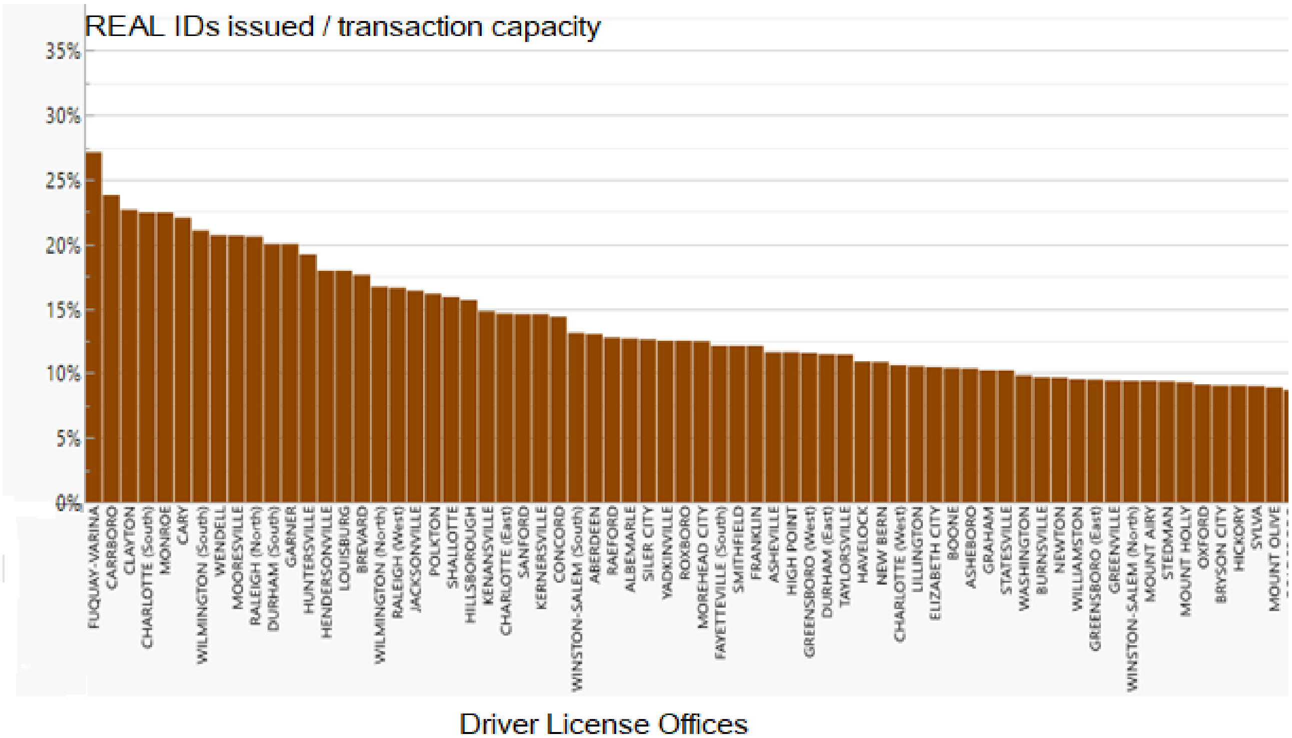


Figure 13. DLOs sorted by highest to lowest traffic and activity

The top five locations for driver license offices with the highest expected net demand are:

1. Durham East
2. Fayetteville West
3. Charlotte North
4. Winston-Salem
5. Greensboro East

As depicted in Figure 13, the highest utilization in terms of the ratio of the total number of REAL IDs issued to service capacity for the period of 2018-2019 is observed in Fuquay-Varina, followed by Carrboro, Clayton, and Charlotte South. The DLOs with the lowest capacity utilization ranking are listed below. Note that one reason for observing low utilization rates in some locations might be the low demand for REAL ID.

1. Elizabethtown (lowest utilization)
2. Sparta
3. Spruce Pine
4. Whiteville
5. Charlotte North

22. Fayetteville West
50. Greensboro East
61. Charlotte West
65. Durham East
114. Fuquay-Varina (highest utilization)

Another measure to identify driver license offices in need of operational improvements or additional resources is the number of days required to fulfill the net REAL ID demand. The top three DLOs with the highest number of days required to fulfill the anticipated demand are Burnsville, Raeford, and Edenton.

For any organization, the waiting time is highly correlated with the service capacity, which is a function of service time and the number of servers. Noting the criticality of the waiting time data, the project team presented a set of candidate locations to DMV Administration in September 2019. The candidate locations to conduct operational efficiency analysis included Durham East, Fayetteville West, or Raeford. On February 18, 2020, the project team was notified with the selection of the North Raleigh Driver License Office as the focus-DLO. This decision is followed by a series of meetings, visits, and observations at the selected DLO.

To understand the relationship between REAL ID demand and the service capacity of the Driver License Offices, the project team observed specific limitations faced by the NCDMV North Raleigh Driver License Office. These limitations are summarized in the subsequent sections.

5.1. Technology Related Limitations

With the intention to perform a comparative analysis of the performance of the driver license offices, the project team wanted to clarify questions such as: How does NCDMV measure the efficiency of a driver license office and compare the performance of different DLOs? What is the efficiency, utilization, and other productivity measures? The following data was requested on September 4, 2019:

- Number of REAL IDs Processed per Staff/per hour/per month
- Number of REAL IDs Processed per terminal/per hour/per month
- Number of REAL IDs Processed per location/per hour/per month
- Cost per REAL ID processed
- Wait Times for REAL ID customers
- Percent of REAL ID Renewals
- Percent of Errors with REAL ID issuance or renewal
- Unlicensed drivers as a percent of licensed drivers
- Percent of License Renewals Done Online
- Number of REAL IDs issued for unlicensed residents
- Number of REAL IDs issued for 15-18-year-old residents
- DMV Queuing system data (wait and serve times, ticket type, transaction time, classification, etc.)

NCDMV's response to our initial data request revealed the technological limitations of their systems. Following quote clearly expresses the inability of the existing queueing system to categorize REAL ID transactions:

> *"DMV has several systems to collect wait and service time. The queuing system alone is focused sole [sic]on queuing and is not tied to transaction and therefore will not provide meaningful wait and service time insight. Operations at DLO offices does [sic] not segregate REAL ID customers."* October 2019.

The data provided by the DMV administration included monthly REAL ID issuance data with location breakdown, QFlow screenshots, and SAS Scorecard data, which was helpful in understanding the processes and staff resources to issue REAL ID. QFlow system has the capability to provide real-time data for the following fields: date, customer number, case number, check-in time (time customer receives ticket/case number at the greeting desk), time customer called for the transaction, time transaction starts, time transaction completed, terminal number. The project team developed a different set of fields to be used during data collection and observations, which resulted in useful insights for process improvements. Having DLEs switch between five different information systems (QFlow, Capture, SADLS, Enforcement, and Inova) for each transaction was identified as an improvement area. Log in and switching from one screen to another prolongs the transaction time to issue REAL ID up to 27 minutes. Streamlining all these systems and eliminating unnecessary tasks in between can potentially reduce the transaction time by 50%.

Another drawback is regarding the current queuing system, QFlow, which creates the first record when the customer meets the greeter. Unfortunately, there is a considerable amount of wait time before a customer is greeted by a DLE, and QFlow cannot capture this wait time. With a simple sensor solution, DMV can collect the actual arrival time of customers. The project team recommends an update to the queueing system to include the following information:

- Customer #
- Time in (customer enters the facility)
- Number of people in the company
- Time to start talking to the receptionist
- Time to get a ticket
- Time to be called for service
- Terminal number
- Transaction start time
- Time documents approved
- Time scanning is completed
- Time Voter registration is completed
- Time Sex offender check is completed
- Payment completed
- Time TDC is printed
- Time customer leaves the terminal

5.2. Workforce Related Limitations

The service capacity of the NCDMV is determined by the transaction time, the number of Driver License Examiners (DLEs), and the number of terminals. Across 14 NCDOT divisions, there are 9 NCDMV districts that manage the 114 Driver License Offices as well as mobile units. As of September 2019, there were a total of 579 Driver License field employees working across 114 Driver License Offices and 8 Mobile Units. Those 579 employees are classified as Chiefs & DM (2), DDM (3), DL Sups (82), DLE II (19), and DLE I (466). Among these classifications, only examiners who have received First-tier, Downstream, and Related entities (FDR) training can issue REAL ID. New employees receive Driver Examiner Basic Training that includes training for many types of transactions, including REAL ID, which is a module within the training curriculum.

Figure 14. NCDOT Divisions Map

One of the reasons for high wait times is the shortage of qualified Driver License Examiners. There is a minimum of a four-week lead time to complete the required training to issue REAL ID. Once new hired Examiners are onboarded, during the REAL ID module of the Driver License Examiner Basic Training curriculum, they are instructed on the Federal guidelines/Federal Register for the requirements and directed to utilize their chain of command, the REAL ID FAQs, and the REAL ID Team service email account for assistance.

NCDMV has a real-time system to measure and monitor the various productivity and performance measures for their workforce at the state, district, and facility or DLO level. At the facility level, the key metrics being used to monitor DLEs' performance include *Completed Service* (number of transactions completed), *DLE Utilization Rate* (time spent actively serving a customer), and *Normalized Service Time* (normalized measure of service speed, service type focuses on the slowest third of transactions). At the state level, additional measurements include *% DLE Absent* (DLEs on vacation or taking time off) and *Hourly Transactions per Active DLE.* By closely monitoring these metrics, the NCDMV keeps increasing its workforce to improve customer service levels. As of May 2020, the total workforce personnel allocated to the Division of Motor Vehicles for administrative and operational staffing, as approved by the Office of State Human Resources and the Department of Transportation, was 1,329. In addition to the workforce expansion, NCDMV should consider reassigning DLEs based on the demand for REAL ID.

5.3. Space Related Constraints

Another important determinant of the service capacity is space availability. For NCDMV, limited physical space at the driver license offices restricts not only the maximum number of terminals that can be added to accommodate additional Driver License Examiners, but also the number of seats in the waiting area. According to our data, the average number of persons accompanying a single customer is two. Occupied seats in the waiting area result in an inconvenience for customers and cause misperceptions with crowding outside.

Currently, there is no system in place to monitor the occupancy rate of the waiting area to detect and eliminate inconveniences for customers. However, our simulation results (with February 2020 data) indicate that North Raleigh Office needs 16 more seats in the waiting area. Suggestions include that

DMV designate a separate area for accompanying people and develop measures to manage the maximum number of customers waiting. Another suggestion is to increase online engagement with customers. If customers who are not applying for REAL ID choose to complete their transactions online, there will be more space for REAL ID customers.

Finally, expansion of the service capacity requires additional space for adding new terminals in the existing facilities. Unfortunately, the social distancing requirements due to the current outbreak will add more restrictions to the capacity expansion efforts of the NCDMV.

5.4. Current Performance Management Framework

A performance management framework should contain a performance measurement plan that identifies specific and outcome-based metrics that help an organization to fulfill its mission. With its commitment to Responsiveness, Efficiency, Performance, Oversight, Restructure, and Transparency (REPORT), the North Carolina Department of Transportation has established the DOT REPORT program, which is a comprehensive performance management framework helping NCDOT to achieve its mission. In this program, *Responsiveness* is associated with addressing structural problems and other reported road hazards in a timely manner. *Efficiency* aims to streamline project delivery and establish baseline unit pricing for transportation goods. *Performance* is associated with increased transparency and responsiveness and measured by the level of satisfaction with transportation services and an annual employee satisfaction survey. *Oversight* involves budget transparency and allows for greater legislative and citizen oversight. *Restructure* covers improving the efficiency and effectiveness of operations and aligning operations and staffing with strategic planning, performance goals, and measures (see Appendix). *Transparency* aims to increase public transparency via performance dashboards, project progress, and traveler information.

As the largest division within NCDOT, NCDMV follows the same REPORT program. For this purpose, NCDMV administrators use the SAS Scorecard System as a performance dashboard. The SAS Scorecard System includes performance metrics retrieved from SADLS and QFlow systems. SAS Scorecard categories and relevant statewide performance metrics as of February 24, 2020, are listed in Table 5. The core performance metrics such as wait times, DLE utilization rate, and percentage of abandoned transactions are far from target levels. The normalized service time, which is a productivity measure, indicates needs for improvement. The accuracy measure "% Matched SADLS to Q-Flow" indicates data inconsistencies between the two systems and acts as a technological limitation that needs improvement.

Note that the number of driver license offices in Table 5 is 108 (N=108). Although NCDMV had 114 offices, SAS Scorecard System was not synchronized with six offices. The missing offices are Lumberton-CDL Office; Pembroke; Raleigh (North); Statesville-CDL Office; Walnut Cove and Yanceyville. Unfortunately, the focus of this project, the North Raleigh Office, was one of the six missing offices.

Table 5. NCDMV SAS Scorecard Dashboard

SAS SCORECARD STATE SUMMARY					
District (1..7) Office (N=108)	Target	Mean	Min	Max	Media
Core Metrics					
Average Wait Time	< 30 min	48			
Average Wait Post-Check-in Wait Time (mins)		38	8.35	84.58	37.90
Average Pre-Check-In Wait Time		10			
% of Transactions Better than Target Service Time	> 90%	76%			
Success Rate		67%	0%	100%	70%
DLE Utilization Rate	> 80%	76%	58%	90%	76%
% DLE Absent		13%	0%	38%	12%
Hourly Transactions per Terminal		2.63	0.55	6.38	2.56
Hourly Transactions per Active DLE		3.27	1.10	6.38	3.08
Average Hourly Volume					
Average Hourly Arrival Volume per Office		11.91	3.51	29.85	10.46
Average Hourly Volume Completed per Office		11.27	3.51	29.22	9.97
% Abandoned and Aborted	<4%	5%	0%	25%	4%
Capacity					
Average # DLEs Working per Office		4.6			
Average # of Terminals per Office		5			
Hourly Average # of Terminals in Use per Office		3.41	1.00	9.15	3.02
Terminal Utilization Rate		73.5%			
Average Hourly Volume to Terminal Ratio		3.50			
Accuracy					
% Matched SADLS to Q-Flow		89.20%			
Productivity					
Normalized Service Time	1.2	1.14	0.73	1.70	1.
Average Transactions per Hour		3.30			
Average Hours Worked per Day		8.2			
DLE Utilization Rate	> 80%	76%			
Volume Drivers					
Real ID Transactions		966152	32%		
Legal Presence		17964	1%		
State Online Transactions					
Completed Online Transactions		706912	24%		
Wait Time Distribution					
% Waits < 15 mins		34%			
% Waits 15-30 mins		16%			
% Waits 30-60 mins		22%			
% Waits 1- 2 hours		19%			
% Waits > 2 hours		8%	0%	28%	

5.4. Proposed Performance Management Framework

With the purpose of aligning NCDMV SAS Scorecard Metrics and the DOT REPORT program, the project team focused on interpreting *responsiveness*, *efficiency*, *flexibility*, and *sustainability* from the perspective of NCDMV's core values and priorities. Thus, we developed a new conceptual performance management framework with a roadmap to success and performance metrics categorized with respect to four competitive dimensions (sustainability, efficiency, and effectiveness, responsiveness, flexibility) and four perspectives (customers, operations, finance, employees). If implemented, the proposed performance metrics would also serve to address some of the concerns in the recent NCDMV Audit Report (2018).

Figure 15. Proposed Performance Management Framework for NCDMV

Different approaches to *responsiveness* exist in the literature, including time-based competition, business process re-engineering, agile manufacturing, and mass customization (Kritchanchai and MacCarthy, 1999). *Efficiency* and *productivity* levels have become a significant managerial issue for service industries. From the DMV's point of view, responsiveness is characterized by the ability to scale up (or down) within strict time limits, and the rapid internalization of consumer choices. Conboy and Fitzgerald (2004) define *flexibility* as "the ability of an entity to proactively, reactively or inherently embrace change in a timely manner, through its internal components and its relationships with its environment." NCDMV has the role of promoting *sustainability* in its services and operations by adopting strategies with a fundamental environmental attitude, use of energy, use of input material, product, packaging, transport, consumption, and waste.

Figure 15 presents the roadmap to success by incorporating customer experience and resource management functions with important success dimensions for NCDMV: responsiveness, efficiency and effectiveness, flexibility, sustainability, accessibility, and technology into a holistic framework.

For implementation, the proposed framework (Figure 15) is supported with a set of next-generation performance metrics Key Performance Indicators (or KPIs) in Table 6. These KPIs are designed to lead and manage DMV facilities and are categorized according to four key dimensions (sustainability, efficiency & effectiveness, responsiveness, and flexibility) and four perspectives (customers, operations, finance, employees). It should be noted that measures in Table 6 are classified as having either customer experience or resource management focus.

Table 6. Proposed Performance Metrics

	Efficiency & Effectiveness (Productivity)		Responsiveness (Consistency)		Sustainability (Accessibility)		Flexibility (Technology)	
Measures	**Customer Experience**	**Resource Management**	**Customer Experience**	**Resource Management**	**Customer Experience**	**Resource Management**	**Customer Experience**	**Resource Management**
Customers	# of customer complaints	# Driver licenses processed	% of customers Served in <15 min	Accuracy of the real-time data	average travel time to access DLO	Format of response to customer inquiries	% services available online	% total transactions completed online
	# of meet or exceed expectations	# of DLEs required for optimal service	Customer Satisfaction Scores	Time to greet customers	Number of mediums for service	Number of services able to render	Ease of switching to different channels	% transactions available online but completed at DLO
	% Reduction in wait time for mailed items	# Licenses processed per staff FTE	% Customer Compliments	# customers returned by the greeter	# of ways to arrange an appointment	Customer service email count	Waiting area entertain-ment technologies	Time required for system maintenance
	Received services that they came for	# Licensed Drivers per DLO and DLE	% Customer returns for incomplete service	# customers greeted per hour	# available seats in the waiting area	Customer service chat count	Utilization rate for chat bots	% of system failures
	average travel time to DLO	Population per DMV License Office FTE	Average resolution time for complaints	# transactions at the mobile units	% of appointment-based transactions	# of social media followers	% transactions done on self-service kiosks	Terminal failure time
	# revisit frequency	% Renewals done online	Total wait time at DLOs	Utilization of mobile units	time for appointment-based transactions	# touch points at the airports	% Licensed drivers with online account	% Matched SADLS to QFlow
	# transaction types	% Unlicensed drivers as of licensed drivers	Wait time at the mobile units	Customer service phone call count		Customer service chat count	% customers interested in pick-up service	difference in transaction time at mobile units and DLOs
Services (Operations)	average hourly arrival volume	DLO and Terminal utilization rates	Informed how to find missing documents	Success rate (accurate transactions)	Availability of mediums for service	% Decrease in service time	Decrease in terminal visits	Number of terminals in use
	Pre-check-in and post-check-in wait time	% of each transaction type inc. REAL ID	Informed about time of service estimate	Standard processing time per transaction	Average service time	Efforts (Cost) related to quality standards	Customer touch points	% Reduction in Turnover
	Total Time in System (min,max, mean, median, mode)	# successful transactions per DLO (hourly/daily/total)	Time to receive documents	Deviation from the standard processing time	Number of chat sessions initiated	Number of corporate social responsibility events	Number of communication mediums	Miles travelled for Flex (Borrowed) Personnel
	Average # Waiting in pre-check-in line	% of Abandoned or aborted transactions	Average # Waiting in post-check-in line	Time to onboard new DLEs	Availability of kiosks	Initiative for eco-friendly mobile units	Time to scan documents	Cloud compatibility
	% of customers served in >30 min	transaction time for each DL type	# arrivals during overtime hours	Total Number of overtime hours	Actual carbon footprint	% recycled material	Time to take photo	% online transactions made via smartphones
	# of Customers left without service	% transactions better than the target service time		Transaction completion rate per overtime hour		Green energy usage	Time to complete voter registration	% online transactions made via computers
Finance	Average price for the services	Total Cost per transaction	Number of available payment options	Total Cost per Licensed Driver	Average travel time from work	Cost of mobile unit support to DLO		Time to complete payment
	Cost of delivering sub-standard service to customers	Cost per license processed	Resources for customers to find needed information	Cost of setting up appropriate information centers	Drive time to DLOs and Mobile Units	Amount of investment in technology	% Reduction in Customer repeat visits (Customer cost)	% Reduction in Overtime Costs
	Total miles traveled of mobile units	Licensing revenues/ by licensing costs	% payment types	Cost of turn arounds	Customer access type (by walk, bike, bus, Uber/Lyft, personal vehicle)	Total website traffic	# of customers prefer online services	Cost of IT integrations
	Average revenue per customer	Cost of FDR training, data collection and analysis	Incentives to divert customers to online services	Cost of training employees to be consistent and accurate	% customers with disabilities	Services available for customers with disability	Cost savings associated with Online customer services	Power consumption; Fuel consumption ($) of mobile units
Employees	Actual time to receive DL	%DLE Absent and % DLE Idle	Consistent information relayed from every employee	Training in more than just their job	Appointment times that let customer receive service instantly	cost of overtime hours	Ease of communication between employees and customers	Training in new technologies
	# transactions/hr/ employee during overtime	Normalized service time	DLE Utilization Rate	Having easy access to view the standards	Employee incentive program	cost of transferring a DLE between office		Average hours worked per day

6. Optimal Reallocation of NCDMV Resources to Meet the REAL ID Demand

After forecasting the REAL ID demand and analyzing the performances of the DLOs, a mixed-integer network optimization model is constructed to select the best capacity expansion option for high-volume offices while keeping the expansion costs and efforts at minimum. Note that capacity expansion options include technology investments to cut service times, personnel reallocation, transfer of mobile units, overtime, or weekend hours. In this section, we present the resource reallocation optimization model that considers REAL ID demand, staffing levels, operational constraints, the travel distance between DLOs, and arrival rate as input parameters. If implemented as a decision-making tool, the proposed optimization model requires real-time data feed from the SAS Scorecard System. The assumptions, notation, model formulation, and the solution are presented below, while data and model results are provided in the Appendix.

The mathematical model works under the following assumptions:

- There are 108 DLOs and 9 mobile units
- The driving distance for each pair of DLO is available
- Demand projection for each DLO is available
- Real-time data feed from SAS Scorecard is available (February 24th instance is used in this report)
- The relative cost or effort for DLE transfer among DLOs, relocating mobile units, and overtime cost is known

Notation:

Input parameters:

i : set index denoting a low-demand DLO sharing its resources

j : set index denoting a high-demand DLO receiving additional resources

C_{ij}^{T} : cost of transferring a DLE from DLO *i* to DLO *j*, proportional to the distance between *i* and *j*

C_j^M : cost of mobile unit support to DLO *j*

C_j^O : cost of overtime hours (4 hours on Saturday) at DLO *j*

DLE_i: number of driver license examiners that can issue a REAL ID at DLO

d_j : forecasted daily demand for REAL IDs at DLO *j*

k_j : hourly transactions per active DLE at DLO *j* (SAS Scorecard metric)

l_j : average hourly arrival volume at DLO *j* (SAS Scorecard metric)

s_j : average hourly volume completed at DLO *j* (SAS Scorecard metric)

N : number of mobile units available

Decision variables:

x_{ij} : number of DLE(s) that should be transferred from DLO *i* to DLO *j*

w_j : binary variable indicating if DLO *j* should have weekend hours (=1) or not (=0)

m_j : binary variable indicating if DLO *j* should have mobile unit support (=1) or not (=0)

Model Formulation

Minimize $\sum_{i,j} C_{ij}^{T} x_{ij} + \sum_j C_j^M m_j + \sum_j C_j^O w_j$ (1)

subject to

$$\sum_i x_{ij} \leq 5 \qquad \forall j \tag{2}$$

$$\sum_i x_{ij} \geq \left\lceil \frac{l_j - s_j}{k_j} \right\rceil \qquad \forall j \tag{3}$$

$$\sum_j x_{ij} \leq DLE_i \qquad \forall i \tag{4}$$

$$p_j = \left(DLE_j + \sum_i x_{ij} \right) k_j + 6m_j \qquad \forall j \tag{5}$$

$$8p_j + 4\, k_j * DLE_j * w_j \geq d_j \qquad \forall j \tag{6}$$

$$p_j \geq l_j \qquad \forall j \tag{7}$$

$$\sum_j m_j \leq N \qquad \forall j \tag{8}$$

$$m_j + w_j = 1 \qquad \forall j \tag{9}$$

$$m_j, w_j \in \{0, 1\} \qquad \forall j \tag{10}$$

$$x_{ij} \in Z \qquad \forall i, j \tag{11}$$

The integer programming model aims to choose the best alternatives for the decision-makers by minimizing the total cost of DLE transfers, the cost of shifting mobile units, and the additional cost of weekend overtime hours as indicated in the objective function equation (1) above. The first constraint listed as equation (2) ensures that no Driver license office can have more than five examiners transferred to their location. Following queuing theory principles, Equation (3) indicates a lower bound on the number of transfers such that service rate is greater than the arrival rate. Equation (4) sets an upper bound on the number of DLEs that can be sent out from a low-demand office. Equation (5) calculates the new service rate after all alternatives are consumed. Equation (6) guarantees a DLO is equipped with enough resources to meet and possibly exceed the daily projected REAL ID demand. Equation (7) aims to eliminate the waiting line explosion by setting the new hourly service rate to a larger value than the hourly arrival rate. Equation (8) indicates the upper bound on the number of mobile units that can be utilized. Equation (9) limits the selection of overtime hours or mobile unit support for each DLO. Finally, the last two equations (10,11) represent the domain constraints for the decision variables.

Analyzing statewide SAS Scorecard data and demand projections, the project team categorized 28 DLOs as high-demand offices that require additional resources and the remaining 81 DLOs as the low-demand offices that can transfer some of their DLEs with high-demand offices until the REAL ID deadline. After populating the real data, the integer programming formulation above resulted in 2,268 integers and 56 binary variables with 277 constraints. Due to limited access to on-campus SAS software, we used Generalized Algebraic Modeling System (GAMS) as the modeling platform and used the NEOS server to solve the model. The results are summarized in Table 7 below.

Table 7. Optimal Reallocation of DLEs, Mobile Units and Extended Hours

High-demand DLOs Receiving Additional Resources

Low-demand DLOs Sharing Resources

DLEs transferred	Asheville	Charlotte East	Charlotte North	Charlotte South	Charlotte West	Clayton	Durham East	Durham South	Edenton	Fayetteville West	Fuquay Varina	Gastonia	Greensboro East	Greensboro West	Henderson	Hendersonville	Monroe	Oxford	Raeford	Raleigh North	Raleigh West	Spruce Pine	White ville	Wilming ton North	Wilming ton South	Winston Salem North	Winston Salem South	Yadkinville
Weekend hours			4				4	4	4	4	4	4	4		4	4		4	4	4	4	4	4		4	4	4	
Mbbile Unit	1	1		1	1	1								1			1							1				1
Aberdeen			1	1			2																					
Wilson	1																											
Louisburg					1																							
Newland		1																										
Sanford						1																						
Burnsville												1																
Cary							3																					
Erwin									1																			
Lincolnton											1																	
Marion										1																		
Newton										3																		
Tarboro								1																				
Elizabethtown																	1											
Fayetteville South													3					1									1	
Goldsboro														1														
Mooresville															1													
Williamston																1												
Tarboro																						1	1					
Franklin																				2								
Hillsborough																			1									
Roxboro																				2								
Salisbury																					1							
Siler City																									1			
Clinton																												2
Clyde																												3
Williamston																										1		
Total	1	1	1	1	1	1	5	1	1	4	1	1	3	1	1	1	1	1	1	4	1	1	1	0	1	1	1	5

The optimization results in Table 7 imply reassigning (i.e., changing the base office) for a total of 43 DLEs (7.4% of the 579) across the state. The solution suggested 19 DLOs, including the North Raleigh Office, to have four overtime hours on Saturdays and suggested using mobile units to support high-demand offices rather than rural parts of the state until the REAL ID deadline. The array indicates specific offices that should receive additional resources and from which location it should be reallocated. Additionally, extra labor hours and mobile unit support are indicated. The table above indicates that the North Raleigh office should receive two DLEs from Franklin and two DLEs from Roxboro with four extended hours allocated for an optimal solution. Another example would be Durham East, which would utilize two DLEs from Aberdeen and three DLEs from Cary and a weekend labor allocation of four additional hours. Neither example office would require Mobile Unit support.

7. Simulation of North Raleigh Driver License Office

The use of simulation models is a low cost and practical way to test various organizational configurations. Modeling a simulation with the implementation of accurate real-world measurements allows for flexible experimentation and analysis. The computer-based simulation utilizes process flows and algorithms to emulate real-world activities at highly accelerated speeds. In this section, we present how simulation can be used to assess the impact of the suggested resource reallocation recommended by the optimization model in the previous section.

Following the basic steps of a simulation study, the project team set the objective of the simulation model as minimizing wait times at the North Raleigh Driver License Office (DLO). The scope of the simulation included the first point of entry to the facility and excluded any process taking place outside the office (e.g., parking). Other excluded processes were driving tests, driving exams, and administrative processes that took place in the back office. Under these assumptions, the project team made multiple visits to analyze the business processes, to collect data, and to build a simulation model based on the process flow chart (conceptual model) presented in Figure 16.

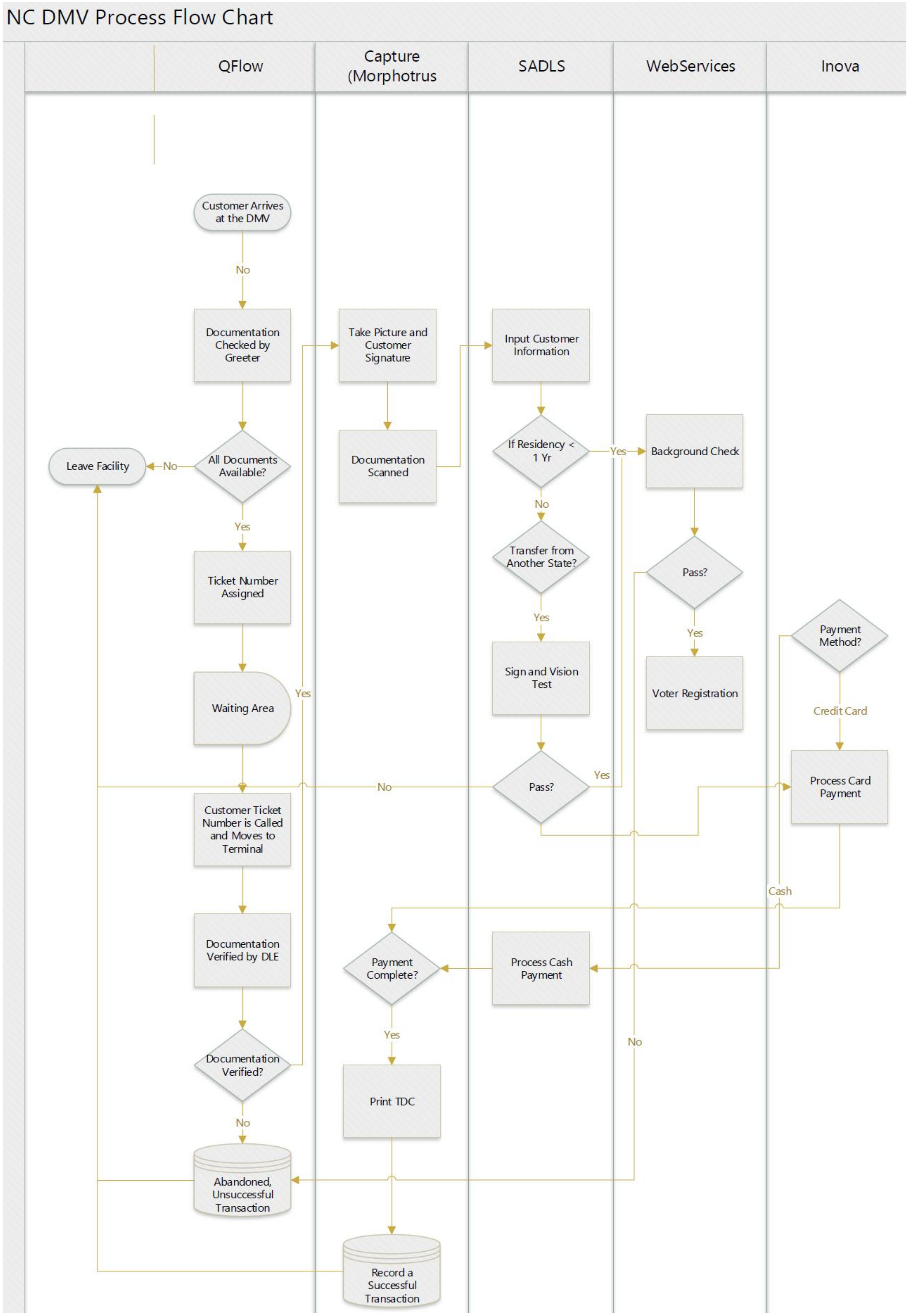


Figure 16. DLO Process Flow Chart

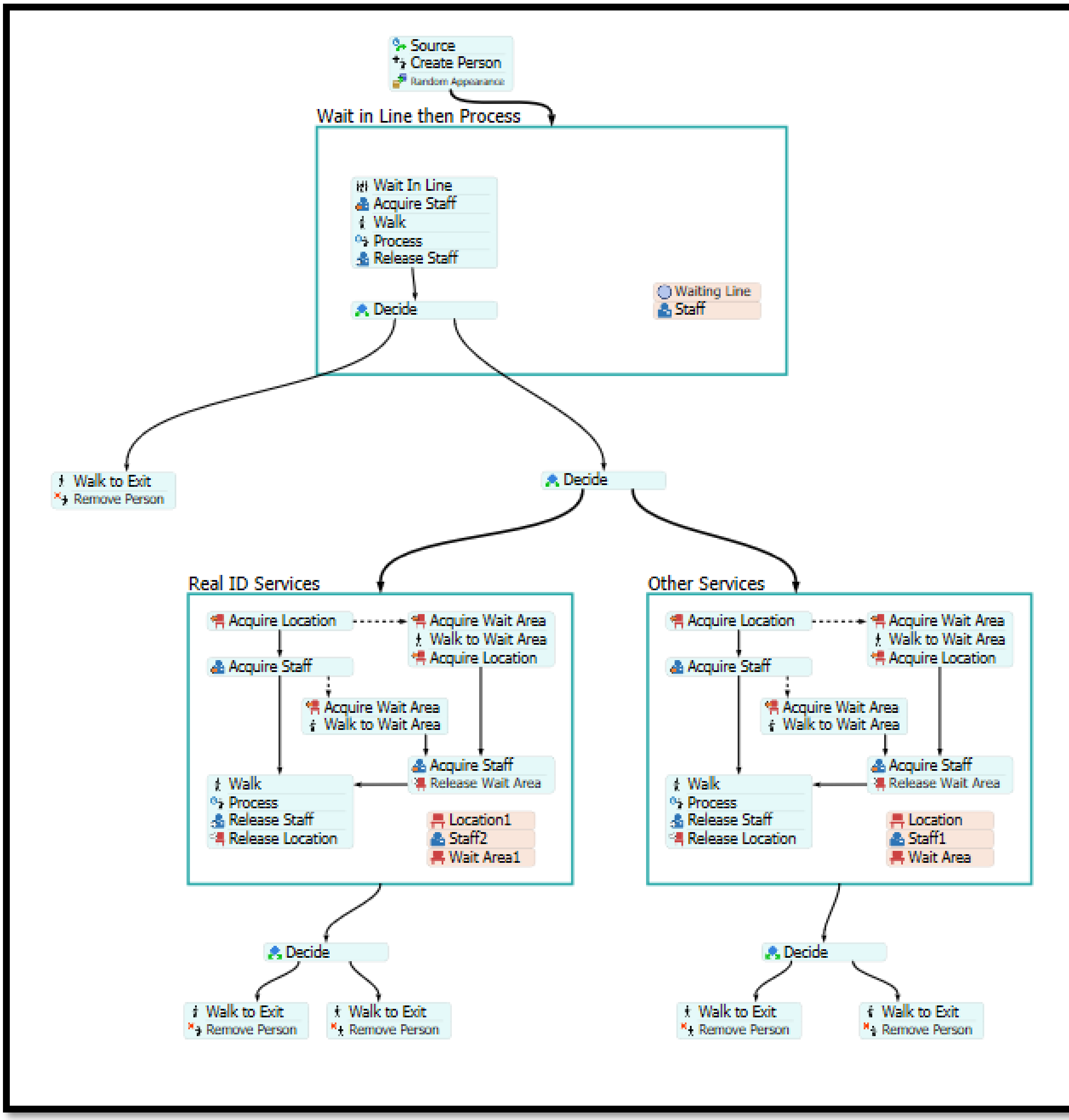


Figure 17. FlexSim Simulation Model Logic

FlexSim 2020 is the platform that was chosen to build the simulation model and execute simulation experimentation. The aim of the FlexSim simulation model displayed in Figure 17 is to closely emulate the daily operation of the driver license office, with the primary goal being the reduction of customer wait times and increased REAL ID issuance. Process flow was constructed to mimic the flow of customers entering the building, waiting in line to have the documentation checked by a greeter, failing documentation check leaving the system, proceed to the waiting area, moving to available REAL ID certified DLE or for other services, and exiting the system.

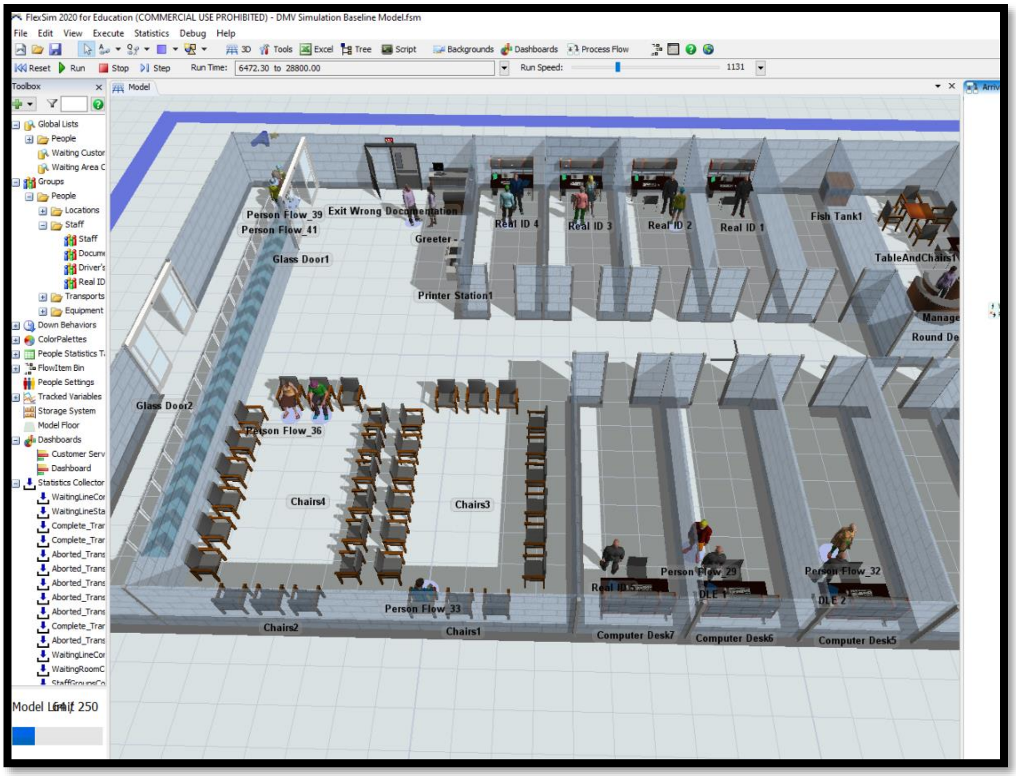


Figure 18. Virtual Model of the North Raleigh DLO in FlexSim 2020

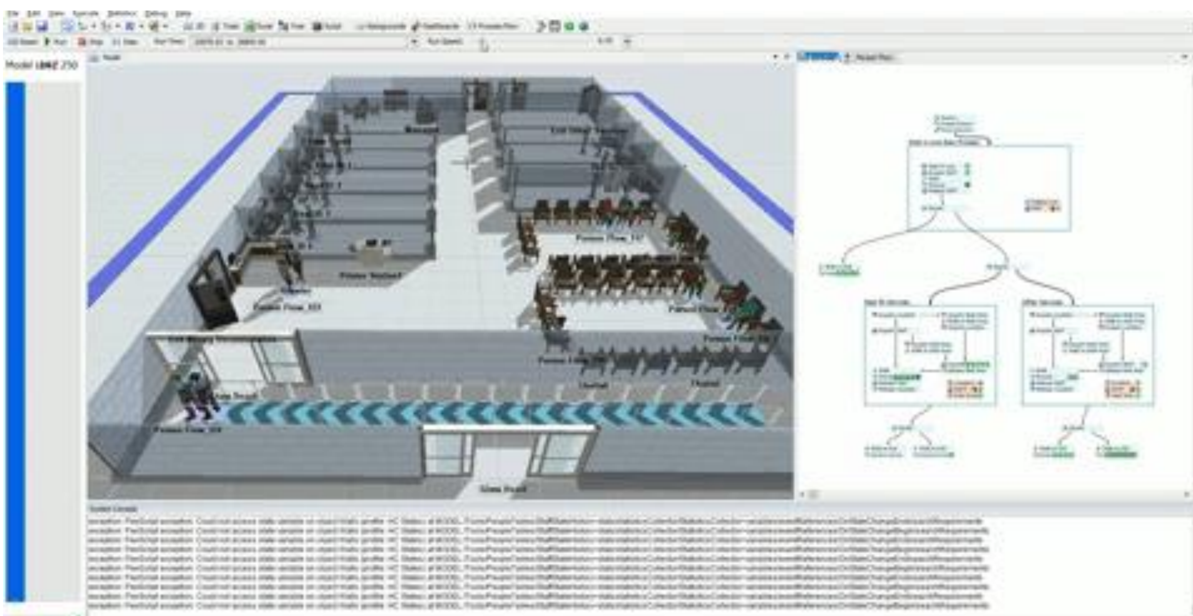


Figure 19. 3D Animation for the North Raleigh DLO Simulation (*Double-click to play animation*)

As a simulation modeling tool, FlexSim provides process flow development options with the ability to link a process flow with a 3D rendered model environment. Companies like Boeing, Lockheed Martin, and Amazon utilize this software for industrial case studies and process improvement. See (https://www.flexsim.com/case-studies) for examples of case studies that have been developed with this platform. A screenshot and animated example of the software's working environment is provided in Figure 18. Also, a clickable 3D animation is embedded into Figure 19.

As customers or entities are created in the system, an accompanying token is created in the process flow and can be monitored as the simulation progresses. Inter-arrival rates of customers, percentage rates that customers possess correct documentation for proof of identity, what service they require, triangular distribution of service speeds for unique staff groups, and percentage rates of customers passing background checks and providing proper payment are based on gathered statistical observations at the North Raleigh DMV License Office. Table 8 contains the input and output statistics of various simulation scenarios that will be further detailed.

Table 8. Simulation Results for the Baseline and Alternative Scenarios

North Raleigh DLO	Real Life	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Simulation Inputs			Add 1 more greeter	System update	Add 1 more DLE	Sys update + add 1 greeter
# DLEs Working	7	7	7	7	8	7
# Greeters	1	1	2	1	1	2
# of Terminals per Office	11	11	11	11	11	11
Arrival Rate Distribution (sec)	N/A	EXP(150)	EXP(150)	EXP(150)	EXP(150)	EXP(75)
Greeting Time Distribution (sec)	N/A	TRI(60, 240, 120)	TRI(60, 240, 120)	TRI(60, 240, 120)	TRI(60, 240, 120)	TRI(60, 240, 120)
Transaction Time Distribution (sec)	N/A	TRI(360, 810, 570)	TRI(360, 810, 570)	TRI(180, 540, 360)	TRI(360, 810, 570)	TRI(180, 540, 360)
Simulation Outputs						
Core Metrics						
Average Wait Time (min)	48	64.53	24.87	6.29	14.98	1.26
Average Post-Check-in Wait Time (min)	38	40.87	24.26	2.23	10.78	0.63
Average Pre-Check-In Wait Time (min)	10	23.67	0.61	4.06	4.20	0.64
DLE Utilization Rate	76%	80%	76%	53%	83%	46%
Greeter Utilization Rate	N/A	94%	49%	58%	97%	48%
% DLE Idle	N/A	21%	25%	97%	20%	54%
Average Hourly Volume						
Average Hourly Arrival Volume (min)	30	24	24	25	24	45
Average Hourly Volume Completed (min)	19	17	19	20	20	42
% Abandoned and Aborted		9%	5%	9%	6%	5%
Average Transactions per Hour	3.2	3.17	3.35	3.23	3.18	8.21
Average Hours Worked per Day	8.2	8	8	8	8	8
Volume Drivers						
Real ID Transactions Completed		135	148	141	139	287
Other Transactions Completed		43	40	40	39	73
Avg Number of people in pre-check in line	N/A	3.7	0.15	7	1.86	1
Max Number of people in pre-check in line	N/A	12	4	20	7	4
Avg Number of people in post-check in line	23	13.27	2.38	54	0.83	0.06
Max Number of people in post-check-in line	N/A	24	6	98	5	3
Average time in the system (min)	61	58	45	31	37	13
Time in the system						
max (min)		127	84	63	94	24
q3 (min)		102	59	43	41	15
med (min)		52	47	28	33	13
q1 (min)		38	28	19	28	12
min (min)		3	2	3	3	2

To verify the model, the process flowchart and the logic of the simulation model was traced through animation together with the NCDOT research team. The users of the model were convinced that the model was built correctly. To validate the model, the output data from the baseline simulation model was compared with real life data (Table 8) by conducting a statistical test. Average post-check-in wait time, DLE utilization rate and average transaction rate per hour were used to validate the simulation model.

Average post-check-in wait time (i.e., 40.87 minutes, σ=9, N=20) was compared with the output observed from the real system, namely 38 minutes (σ=16, N=108), using Student's t-test at 0.05 level of significance and no statistically significant difference was observed between the simulation model and the real system. Similarly, the difference between simulated versus actual DLE utilization rate and average transaction rate per hour was not statistically significant.

After the baseline scenario has been verified and validated by using data collected during our observations as well as SAS Scorecard data provided, four alternative scenarios were tested in the simulation. The baseline scenario is the as-is situation and contains one greeter that checks documents, five employees that can provide DLE services including REAL ID, and two employees that can provide all services except for REAL ID. Four alternative scenarios were simulated:

1. Alternative scenario one adds a greeter for a total of two personnel that can check customer documentation.

2. Alternative scenario two has the same number of personnel as the baseline scenario but reduces the service time required by all DLEs by 50% under the assumption that technological improvements and capture, scan, voter registration, and payment systems would greatly reduce the time required for DLEs to execute necessary steps to render services.

3. Alternative scenario three adds one extra employee to the baseline that can issue REAL ID.

4. Alternative scenario four adds an extra greeter checking documentation for a total of two greeters and reduces DLE service time by 50% under the same assumption as scenario two.

The alternative scenario that provided the best results was scenario four. This is promising since it only involves adding one employee that can verify documentation for proof of identity, relatively less training that is increasing REAL ID certified employees, and the improvement of information technology infrastructure. In fact, the simulation had to double the flow of customers in order to truly test the capability of this design. Even with double the customer foot traffic, there was little to no wait time.

Based on the SAS Scorecard data provided, the average number of hourly transactions is 3.2, which implies 18.75 minutes per transaction on average. At this rate, NCDMV can complete 1639 transactions in all 512 terminals per hour, and it would take 1717 hours or 215 days to satisfy the projected REAL ID demand of 2,813,167. Obviously, at the current rate, the original October 2020 deadline was not attainable. However, extension due to COVID-19 gives NCDMV approximately 300 business days to satisfy all the REAL ID demand. In the case of the original deadline, our simulation suggested implementing scenario four, which would double the number of transactions completed and cut the number of days required to fulfill the demand approximately by half. Additionally, implementing reallocation strategies suggested by our optimization model would have ensured meeting the demand in 95 days.

8. Recommendations to NCDOT

8.1. Next-Generation Organizational Intelligence Platform

The overall outcome of this project was to design a cloud-based, real-time Next-Generation Organizational Intelligence Platform for NCDMV with the feature to be built on their existing programs such as DOT REPORT and SAS Scorecard System. The proposed integrated, real-time time system would consist of state-of-the-art business intelligence and data analytics tools, including SAS Analytics, ArcGIS, SAS Optimization, and simulation. In addition to the alignment of organizational goals and objectives, the new system provides a more customer-centric approach to NCDMV by increasing its transparency and accountability.

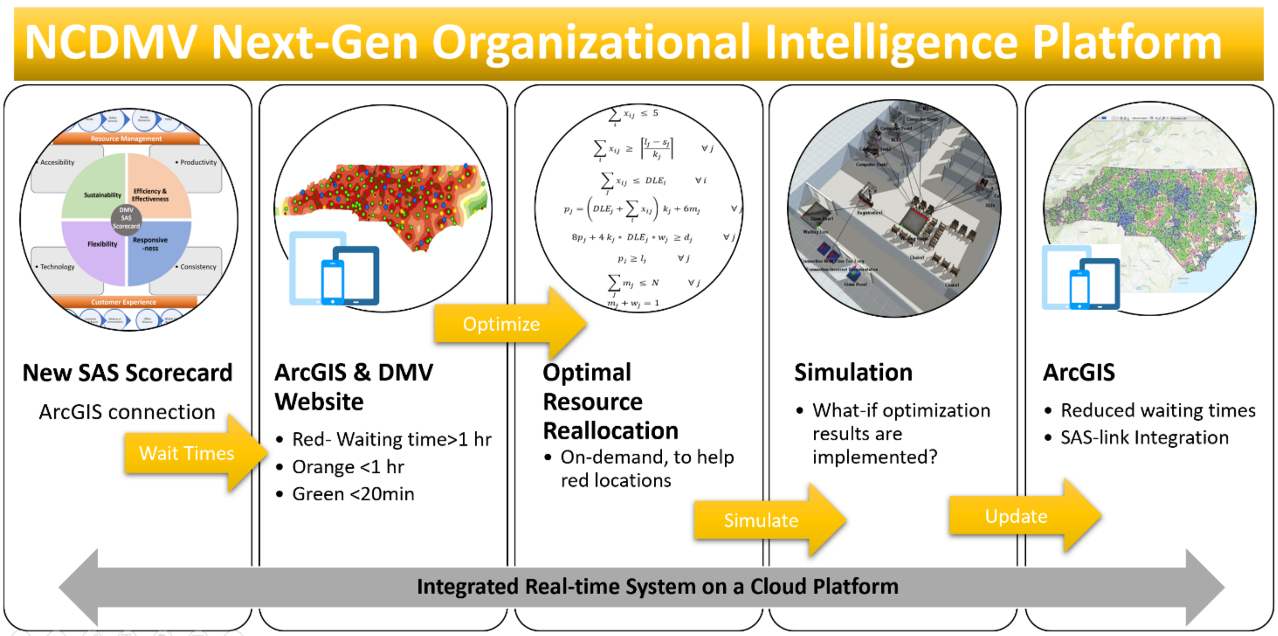


Figure 20. NCDMV Next-Generation Organizational Intelligence Platform

Figure 20 illustrates the components of the NCDMV Next-Generation Organizational Intelligence Platform that shares the DLO wait time information with the public by publishing interactive ArcGIS maps through their web portals. Publicly sharing real-time, DLO statistics would encourage customers to prefer low-volume locations, thus help DMV to better manage the demand. Improved demand management alleviates crowds to some degree but cannot change the total demand. Therefore, in addition to relocating demand, NCDMV should consider strategically relocating its critical resources such as DLEs, mobile units, and overtime hours. For this purpose, we developed the resource reallocation optimization module that will be integrated into the SAS Scorecard and QFlow system. After evaluating the optimal reallocations suggested, decision-makers will have the capability to assess the impact by simulation and visualize them via ArcGIS.

In addition, the project team has following recommendations for the NCDMV Administration:

1. Increase DLOs' operational performance rather than opening new facilities
2. Have a digital marketing plan to manage the demand for the REAL ID

3. Start an incentive mechanism to award the best performing DLO (not DLE).
4. Consider redesigning SAS Scorecard system using the proposed performance management framework
5. Integrate ArcGIS with SAS Scorecard and QFlow Systems to visualize the statewide system performance and to make better decisions
6. Speed up digital transformation by renovating existing legacy systems
7. Train and upskill DMV workforce
8. Improve QFlow or replace with a more comprehensive and flexible queuing system that can collect foot traffic data through IoT applications (see Section 5.1 for recommended fields for QFlow)
9. Monitor the occupancy rate of the waiting area and designate a separate area for accompanying people
10. Focus on multiple statistical measures mean, median, min, max, rather than considering the average values only. Some DLEs can complete more than six transactions per hour while the majority completes 2-3.

8.2. COVID-19 Implications

Unfortunately, most of the project tasks have been performed prior to the COVID-19 outbreak, which had a tremendous impact on people's lives and organizations globally. Unsurprisingly, the global pandemic impacted our team's access to technology available on campus, the ability to meet, travel and collect further data. While we were scheduled to complete the project on time, social distancing due to COVID-19 disrupted DMV operations and NC. Department of Motor Vehicles driver license offices was closed on Wednesday, March 18. Note that the data and results provided in this report took place before the onset of the pandemic. However, there are still serious implications of the COVID-19 on this project.

The biggest impact of COVID-19 is the extension of the REAL ID Federal enforcement deadline. Note that the main motivation for this project was to ensure that all North Carolinians who need REAL ID would get high-quality service by the October 2020 deadline. However, due to the pandemic and the national emergency declaration, the Department of Homeland Security has extended the REAL ID enforcement deadline by a year. The new deadline for REAL ID enforcement is October 1, 2021.

Another impact is the reassessment of the need for the new DLOs. While this project was about opening new DMV locations, ironically, NCDMV shut down many of its existing locations. Therefore, the one-year extension on the federal deadline caused significant changes not only on DMV's operations but also in demand for REAL ID. Backed up demand during shutdown brought an additional surge in demand. However, rapid digitization of the economy resulted in reduced demand for business travel and consequently postponement of the need for REAL ID. On the other hand, increased unrest and the post-pandemic situation will be increasing the need for more reliable, secure identification options like a REAL ID.

Future simulations could involve the implementation of social distancing and distanced seating in response to COVID-19. This would provide insights into the effects of these changes for daily operations prior to real-world implementation.

8.3. Future Steps to Explore

The original objective was to minimize the number of new DMV offices to be opened by efficient use of existing resources under normal (pre-COVID-19) conditions. Under post-pandemic conditions, NCDMV Administration might have new priorities such as the health and well-being of its customers and employees in addition to minimizing waiting times at high-demand locations, focusing on metropolitan areas to ensure they meet the October 2021 deadline, leveraging capacity utilization across all locations.

As for the future steps to explore, we recommend following:

- Post-pandemic demand analysis using surveys and data mining
- Demand projection and location analysis based on 2020 U.S. Census data
- To create and run additional simulation scenarios
- To perform sensitivity analysis
- To develop a SAS code to use SAS PROC OPTMODEL
- To design GUI and custom reports for different user groups
- To analyze the efficiency of DLOs by simulating appointment based DLO operations
- To simulate various layout alternatives to see the impact of social distancing on DLO performance
- To develop a simulation-optimization approach to optimize the reallocation of resources
- To provide training for the NCDMV personnel to use the proposed tools

9. Implementation and Technology Transfer Plan

Early involvement of the potential users was the essential component in developing the research outputs of this project. The project team worked closely with NCDOT to characterize the user needs and to understand the current system capabilities. The work in progress presented during several meetings with the NCDMV received positive feedback in terms of assessing the need for the proposed platform, which will be used by the NCDMV Commissioners, Regional Chief Examiners, the Directorate of Planning and Programming, and the Directorate of Performance Metrics & Management. Either as a standalone tool or as an integrated tool to their decision support system, proposed technology can be considered as modernization of the existing technology.

Technology adoption decision requires review and discussion of the proposed technology in a meeting with the participation of all potential users and the implementation team. Implementation of the new performance management framework; integration between SAS Scorecard and ArcGIS; deployment of simulation and reallocation optimization can be evaluated separately or in an integrated cloud platform. The project team has already addressed various questions by potential users and available to provide additional analysis if more information is needed.

If expected benefits and the technical requirements of the technology are compatible with the functionality of the existing system, then the next step will be experimentation in real user settings but on limited basis. At this stage, implementation of the new performance management framework and integration between SAS Scorecard, ArcGIS, and NCDOT web portals will require collaboration among researchers, users, IT, SAS, ArcGIS, QFlow and SADLS. The proposed animated 3D simulation might be used as a marketing and promotion material. However, its deployment may require FlexSim license. Similarly, proposed optimization model requires integer programming solver such as CPLEX or SAS OR. In either case, it should be integrated to SAS Scorecard and QFlow systems.

Once the small-scale implementation is tested and validated, implementation team and potential users need to identify and work closely with the relevant standards-setting bodies. For the best user experience, acceptance and adoption, custom GUI designs and APIs need to be developed. Especially simulation and optimization implementation require technical training and written users-guide if the new technology is to succeed. If NCDOT staff do not have the required expertise, research team can deliver a hands-on training or workshop.

A successful implementation and technology transfer require strong commitment from senior management; adequate funding; user participation and satisfaction; collaboration among users, researchers, vendors; periodical assessment of the achievements due to new technology. The advantages of the potential technology will be assessed by reduced wait times, improved DLE utilization, increased customer satisfaction and issuing 3 million REAL IDs by October 2021. Research team will be available for additional training and implementation activities to integrate the proposed platform into decision support systems of the NCDMV.

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APPENDIX

APPENDIX A. Additional Details for Location Analysis

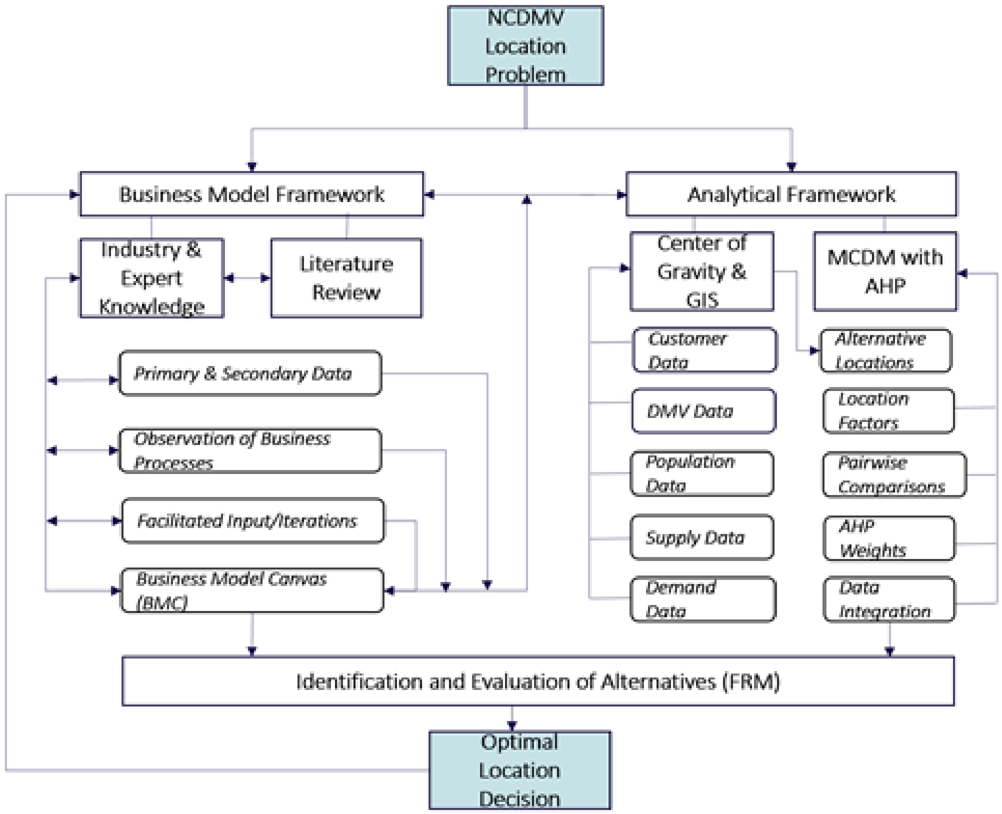
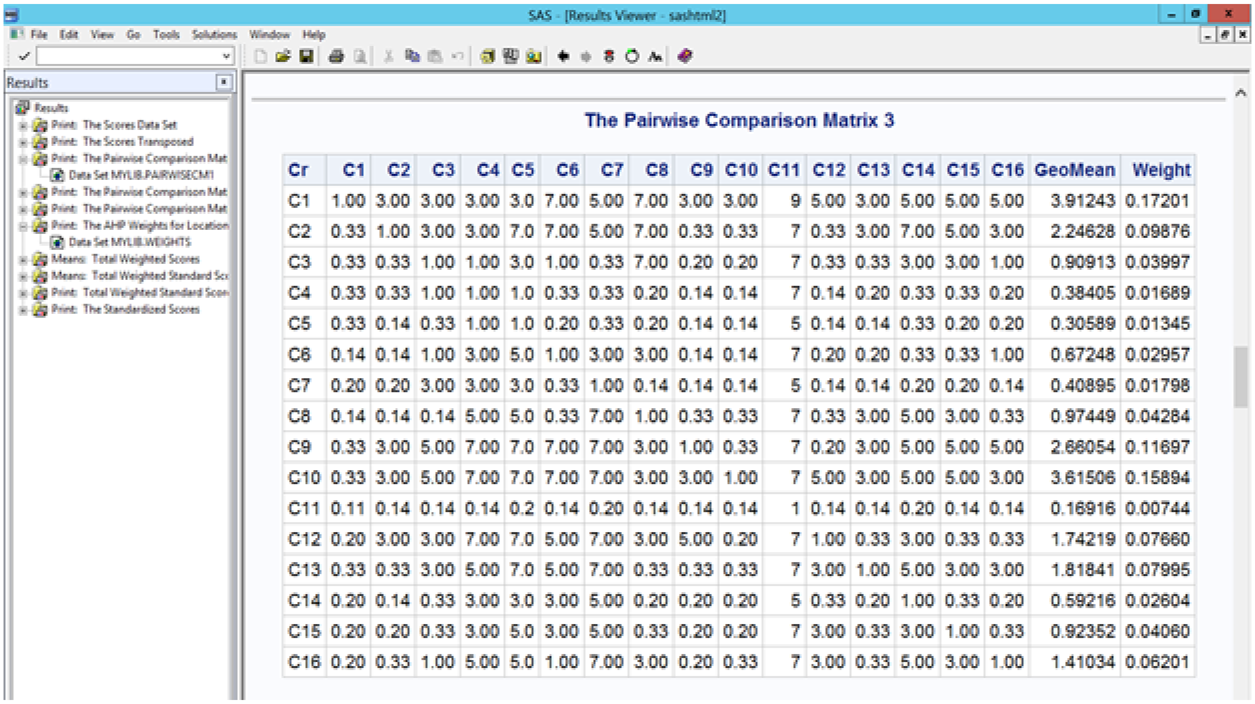


Figure A-1. Expert Knowledge and Evidence-Based Location Methodology

Table A-1. AHP Preference Scale

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally
3	Moderate importance	Experience and judgment slightly favor one Factor over another
5	Strong importance	Experience and judgment strongly favor one Factor over another
7	Very strong or demonstrated importance	A factor is favored very strongly over another, its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one factor over another is of the highest possible order of affirmation.
Reciprocals of above	If factor *i* has one of the above nonzero numbers assigned to it when compared with factor *j*, then *j* has the reciprocal value when compared with *i*	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit



The Pairwise Comparison Matrix 3

Cr	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	GeoMean	Weight
C1	1.00	3.00	3.00	3.00	3.0	7.00	5.00	7.00	3.00	3.00	9	5.00	3.00	5.00	5.00	5.00	3.91243	0.17201
C2	0.33	1.00	3.00	3.00	7.0	7.00	5.00	7.00	0.33	0.33	7	0.33	3.00	7.00	5.00	3.00	2.24628	0.09876
C3	0.33	0.33	1.00	1.00	3.0	1.00	0.33	7.00	0.20	0.20	7	0.33	0.33	3.00	3.00	1.00	0.90913	0.03997
C4	0.33	0.33	1.00	1.00	1.0	0.33	0.33	0.20	0.14	0.14	7	0.14	0.20	0.33	0.33	0.20	0.38405	0.01689
C5	0.33	0.14	0.33	1.00	1.0	0.20	0.33	0.20	0.14	0.14	5	0.14	0.14	0.33	0.20	0.20	0.30589	0.01345
C6	0.14	0.14	1.00	3.00	5.0	1.00	3.00	3.00	0.14	0.14	7	0.20	0.20	0.33	0.33	1.00	0.67248	0.02957
C7	0.20	0.20	3.00	3.00	3.0	0.33	1.00	0.14	0.14	0.14	5	0.14	0.14	0.20	0.20	0.14	0.40895	0.01798
C8	0.14	0.14	0.14	5.00	5.0	0.33	7.00	1.00	0.33	0.33	7	0.33	3.00	5.00	3.00	0.33	0.97449	0.04284
C9	0.33	3.00	5.00	7.00	7.0	7.00	7.00	3.00	1.00	0.33	7	0.20	3.00	5.00	5.00	5.00	2.66054	0.11697
C10	0.33	3.00	5.00	7.00	7.0	7.00	7.00	3.00	3.00	1.00	7	5.00	3.00	5.00	5.00	3.00	3.61506	0.15894
C11	0.11	0.14	0.14	0.14	0.2	0.14	0.20	0.14	0.14	0.14	1	0.14	0.14	0.20	0.14	0.14	0.16916	0.00744
C12	0.20	3.00	3.00	7.00	7.0	5.00	7.00	3.00	5.00	0.20	7	1.00	0.33	3.00	0.33	0.33	1.74219	0.07660
C13	0.33	0.33	3.00	5.00	7.0	5.00	7.00	0.33	0.33	0.33	7	3.00	1.00	5.00	3.00	3.00	1.81841	0.07995
C14	0.20	0.14	0.33	3.00	3.0	3.00	5.00	0.20	0.20	0.20	5	0.33	0.20	1.00	0.33	0.20	0.59216	0.02604
C15	0.20	0.20	0.33	3.00	5.0	3.00	5.00	0.33	0.20	0.20	7	3.00	0.33	3.00	1.00	0.33	0.92352	0.04060
C16	0.20	0.33	1.00	5.00	5.0	1.00	7.00	3.00	0.20	0.33	7	3.00	0.33	5.00	3.00	1.00	1.41034	0.06201

Figure A-2. Screen Capture for the Pairwise Comparison.

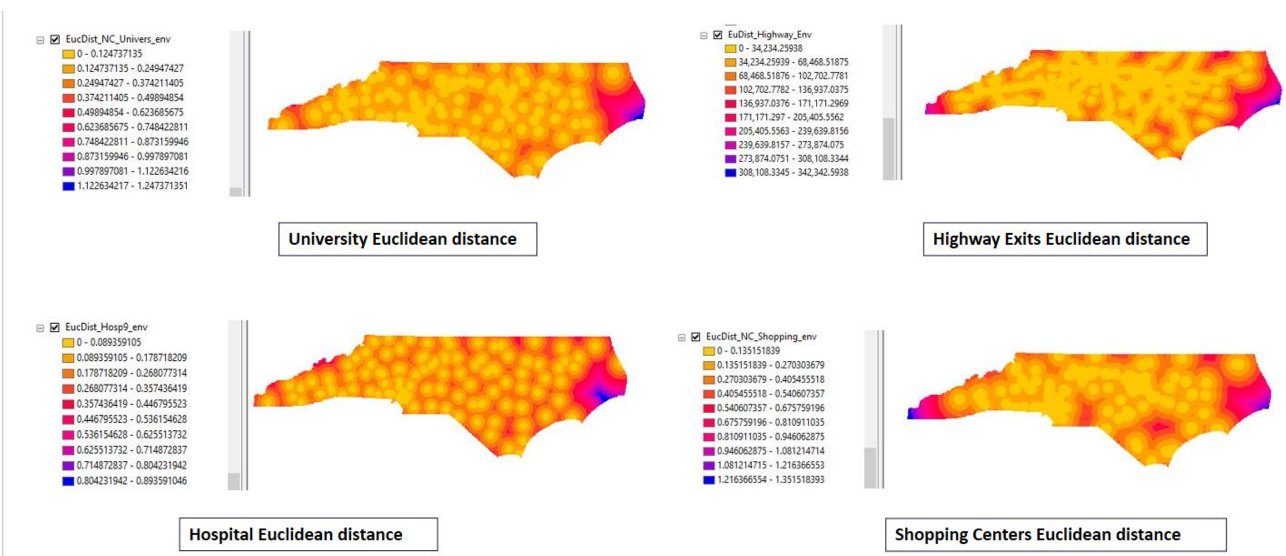


Figure A-3. Euclidean Distance Raster Conversion Output for the Location Criteria

Table A-2. Data Sources for the scoring

Location Criteria	Data Type	Data Source
Population Density	County Data of 15+ years	https://www.census.gov/cgi-bin/geo/shapefiles/index.php
Proximity to existing Locations	GeoCoordinates	NCDMV Website
Proximity (#) to Shopping Malls	GeoCoordinates	https://mallseeker.com/state.aspx?sid=28&mt=0&sortby=dist
Proximity to Hospitals	GeoCoordinates	http://www.ushospitalfinder.com/hospitals/search?search_query=28115&lng=-80.78794069999998&lat=35.584285&cgeo=
Proximity to Universities	GeoCoordinates	https://www.cfnc.org/pay/collegeworks/colleges_map.jsp
Proximity to Highway Exits	GeoCoordinates	ArcGIS Online
Cost of Living	GeoCoordinates	https://www.bestplaces.net/find/state.aspx?state=nc
Housing Rent (Avg County)	GeoCoordinates	https://www.bestplaces.net/find/state.aspx?state=nc
Housing value	GeoCoordinates	https://www.bestplaces.net/find/state.aspx?state=nc
County Overall Tax Rates (sales)	GeoCoordinates	'https://wallethub.com/edu/best-worst-states-to-be-a-taxpayer/2416/
AllTransit Performance Score - mass transit infrastructure (county)	GeoCoordinates	https://alltransit.cnt.org/
Natural Disaster Index	GeoCoordinates	https://ncdp.columbia.edu/library/mapsmapping-projects/us-natural-hazards-index/
Unemployment	GeoCoordinates	https://www.bestplaces.net/find/state.aspx?state=nc
Recent Job Growth (over past Year)	GeoCoordinates	https://www.bestplaces.net/find/state.aspx?state=nc
Future Job Growth (Over the next 10 years)	GeoCoordinates	https://www.bestplaces.net/find/state.aspx?state=nc
Clean energy index - Capacity (MW) (County)	GeoCoordinates	https://energync.org/maps/
Number of Companies with 500+ Employees (2011)	GeoCoordinates	'https://www.sba.gov/advocacy/firm-size-data

Table A-3. ArcGIS Service Area Network Data Export

License Office	Address	Service Area (Mins)	Sum_POPULATION_2017	Sum_AGE_15	Sum_AGE_20	Sum_AGE_25	Sum_AGE_35
ABERDEEN	521 South Sandhills Boulevard 28	Location 1 : 0 - 15	32635	1684	1353	3132	3551
ABERDEEN	521 South Sandhills Boulevard 28	Location 1 : 15 - 20	19429	1142	871	1862	2267
ABERDEEN	521 South Sandhills Boulevard 28	Location 1 : 20 - 30	23657	1412	1117	2531	2741
AHOSKIE	DMV Building, 242 NC 42 W 2791	Location 2 : 0 - 15	14481	1104	905	1615	1753
AHOSKIE	DMV Building, 242 NC 42 W 2791	Location 2 : 15 - 20	14958	1165	930	1626	1822
AHOSKIE	DMV Building, 242 NC 42 W 2791	Location 2 : 20 - 30	20542	1441	1171	2235	2585
ALBEMARLE	DMV Building, 611 Concord Road	Location 3 : 0 - 15	27491	1882	1607	2902	3648
ALBEMARLE	DMV Building, 611 Concord Road	Location 3 : 15 - 20	24233	1648	1286	2340	3254
ALBEMARLE	DMV Building, 611 Concord Road	Location 3 : 20 - 30	18353	1195	859	1741	2481
ANDREWS	1440 Main St. 28901	Location 4 : 0 - 15	6923	391	283	681	789
ANDREWS	1440 Main St. 28901	Location 4 : 15 - 20	9153	520	377	900	1062
ANDREWS	1440 Main St. 28901	Location 4 : 20 - 30	18621	1014	745	1702	2056
ASHEBORO	DMV Building, 2754 US Hwy 220,	Location 5 : 0 - 15	38886	2552	2234	4503	5526
ASHEBORO	DMV Building, 2754 US Hwy 220,	Location 5 : 15 - 20	26882	1819	1437	2822	3904
ASHEBORO	DMV Building, 2754 US Hwy 220,	Location 5 : 20 - 30	20990	1365	1092	2127	2989
ASHEVILLE	DMV Building, 1624 Patton Avenu	Location 6 : 0 - 15	83700	4487	5005	10703	10268
ASHEVILLE	DMV Building, 1624 Patton Avenu	Location 6 : 15 - 20	47809	2584	2251	4862	5721
ASHEVILLE	DMV Building, 1624 Patton Avenu	Location 6 : 20 - 30	40580	2267	1931	3968	4877
BOONE	4469 Bamboo Rd., Suite 103 286(	Location 7 : 0 - 15	24354	2562	4604	2378	2260
BOONE	4469 Bamboo Rd., Suite 103 286(	Location 7 : 15 - 20	14696	836	1345	1544	1767
BOONE	4469 Bamboo Rd., Suite 103 286(	Location 7 : 20 - 30	14652	800	812	1528	1881
BREVARD	50 Commerce St. Unit 4 28712	Location 8 : 0 - 15	17692	1022	861	1526	1870
BREVARD	50 Commerce St. Unit 4 28712	Location 8 : 15 - 20	14562	775	583	1222	1612
BREVARD	50 Commerce St. Unit 4 28712	Location 8 : 20 - 30	16091	859	658	1389	1813

APPENDIX B. 2019-2020 NCDOT Performance Goals and Measures

Performance Measure	How We Measure It	Target
GOAL 1: Make Transportation Safer		
Serious Injury Rate	Total statewide serious injuries per 100 million vehicle miles traveled	≤ 4.09
Fatality Rate	Total statewide fatalities per 100 million vehicle miles traveled	≤ 1.15
Safety Belt Usage	Percentage of surveyed North Carolina drivers using a safety belt	≥ 92%
GOAL 2: Provide GREAT Customer Service		
Customer Satisfaction	Percentage of surveyed customers satisfied with transportation services in North Carolina	≥85%
DMV Wait Time	Average customer wait times at DMV facilities once the customer checks in (in minutes)	≤30 Min.
Visitor Center & Rest Area Condition	Average rest area condition scores	≥92
GOAL 3: Deliver and Maintain our Infrastructure Efficiently and Effectively		
Project Development (STIP)	Percentage of planned STIP projects let on schedule	≥90%
Project Development (non-STIP)	Percentage of non-STIP projects let on schedule	≥90%
Construction Projects – Schedule	Percentage of construction projects completed on schedule	≥90%
Construction Projects – Budget	Total budget overrun for completed construction projects	≤5%
Bridge Health	Percentage of bridges rated in good condition	≥80%
Pavement Health	Percentage of pavement miles rated in good condition	≥80%
Structurally Deficient Bridges	Percentage of bridges that are considered structurally deficient	≤10%
Environmental Compliance	Average statewide environmental compliance score on construction and maintenance projects	≥7.5
GOAL 4: Improve the Reliability and Connectivity of the Transportation System		
Interstate Reliability	Interstate travel time index	≤1.02
Ferry Service Reliability	Percentage of planned ferry runs completed as scheduled	≥95%
Rail Service Reliability	Percentage of planned passenger trains arriving on schedule (*Carolinian* and *Piedmont* only)	≥75%
Non-Reoccurring Congestion	Percentage of reported motor vehicle crashes cleared within 90 minutes	≥85%
GOAL 5: Promote Economic Growth Through Better Use of our Infrastructure		
Program Delivery	Total cash balance (on July 1, 2020)	≤$750M
Diversity Spending	Percentage of the total program budget paid to self-reported minority- and women-owned businesses	≥12.0%
External Expenditures	Percentage of NCDOT's total budget expended on external goods, materials, and services	≥70%
Internal Administrative Costs	Percentage of the overall budget for administrative costs	≤7.6
GOAL 6: Make our organization a great place to work		
Employee Retention	Percentage of employees retained after three years of employment	≥90%
Employee Safety	Weighted index score for employee injury rates, equipment accident rates and workers compensation claim rates	≤6.16
Employee Engagement	Employee engagement survey score	≥5.25

APPENDIX C. Input Data and Optimization Model Results

Table C-1. Data for Input Parameters

	Office	Daily demand	l(j) Average Hourly Arrival Volume per Office	s(j) Average Hourly Volume Completed per Office	DLE(j) Number of DLEs	k(j) Hourly Transactions per Active DLE	Number of Terminals	Hourly Average # of Terminals in Use per Office	Average Hourly Transactions per Terminal
HD	Durham East	252	13.8	13.5	5.0	2.7	6	4.8	2.2
HD	Fayetteville West	236	16.1	14.8	5.0	2.8	9	5.0	1.7
HD	Yadkinville	222	7.1	6.8	3.0	2.8	8	2.5	2.3
HD	Charlotte South	203	26.9	25.0	8.0	3.1	10	7.4	2.6
HD	Greensboro East	200	14.8	14.2	4.0	3.1	7	4.0	2.0
HD	Charlotte North	197	21.4	21.0	8.0	2.5	15	7.5	1.4
HD	Gastonia	172	15.2	14.6	5.0	3.0	6	4.3	2.5
HD	Asheville	155	22.0	20.3	8.0	2.6	12	7.2	1.7
HD	Oxford	151	9.7	9.3	2.0	4.8	3	1.9	3.1
	Graham	150	16.2	15.8	5.0	3.3	6	4.6	2.6
HD	Greensboro West	148	25.6	25.0	8.0	2.7	12	7.7	2.0
HD	Charlotte East	147	25.0	23.6	8.0	2.7	11	7.9	2.2
	Kernersville	146	11.4	10.8	4.0	3.1	5	3.3	2.2
	High Point	139	17.9	17.3	5.0	3.9	6	4.2	2.9
HD	Winston Salem Sou	139	18.8	18.6	6.0	2.8	6	5.5	2.3
	Wilson	135	12.0	11.6	4.0	2.5	6	3.6	1.7
HD	Hendersonville	134	12.7	11.3	4.0	2.9	5	3.8	2.4
	Hickory	132	13.6	13.5	6.0	2.5	6	5.0	2.2
	Lincolnton	132	8.6	7.6	3.0	2.9	4	2.8	2.1
	Shelby	132	9.5	8.7	3.0	2.9	5	3.0	1.8
	Wentworth	128	12.7	12.2	5.0	2.8	4	4.1	2.0
	Concord	127	19.3	19.0	6.0	2.8	7	5.8	2.7
	Louisburg	127	10.1	9.1	3.0	3.6	3	2.5	3.1
HD	Raeford	126	7.5	7.2	2.0	4.3	2	1.7	3.7
HD	Raleigh North	120	30.0	19.0	7.0	3.2	11	7.0	3.5
HD	Whiteville	117	9.3	9.1	2.0	4.8	6	1.9	3.0
	Troy	115	5.7	5.5	2.0	3.3	4	1.6	2.7
	Mount Holly	114	11.6	11.2	5.0	2.6	5	4.3	2.3
	Erwin	112	8.6	8.5	3.0	3.4	3	2.4	2.8
	Salisbury	112	12.9	12.8	5.0	3.0	6	4.1	2.1
	Morganton	111	10.5	10.0	4.0	3.0	5	3.2	1.9
	Hudson	109	11.7	11.6	4.0	2.6	5	3.0	1.6
	Goldsboro	108	13.7	13.7	5.0	2.7	5	4.3	2.6
	Elkin	107	5.4	5.3	3.0	2.5	3	2.2	1.8
	Sanford	107	9.7	8.1	3.0	2.9	3	2.7	3.2
	Mooresville	105	13.3	12.7	4.0	3.0	4	3.6	3.2
	Kinston	104	9.4	8.7	4.0	2.9	5	3.1	1.8
HD	Monroe	104	27.8	26.0	8.0	2.7	9	7.8	2.7
	Garner	103	14.2	13.7	5.0	3.0	5	4.0	2.9
	Asheboro	102	11.7	11.4	4.0	3.0	5	3.4	2.2
HD	Winston Salem Noi	102	15.0	14.7	5.0	3.3	6	4.4	2.4
	Jacksonville	100	15.5	13.4	6.0	2.4	7	5.3	2.0
	Rocky Mount	100	12.5	12.1	4.0	3.3	5	3.7	2.5
HD	Charlotte West	99	21.6	21.0	7.0	2.6	11	6.9	1.9
	Mocksville	98	8.6	8.2	2.0	4.1	3	1.9	2.6
	Lillington	96	7.0	7.0	2.0	3.7	2	1.8	3.5
	Fayetteville South	94	16.5	14.5	5.0	2.6	6	4.9	2.5

Table C-2. Pairwise Driving Distance Data between DLOs (in miles)

IN_FID Name	NEAR_FID Name	i	j	Distance
ABERDEEN	RAEFORD	DLOg1	DLOr19	19
ABERDEEN	FAYETTEVILLE West	DLOg1	DLOr10	35
ABERDEEN	FUQUAY-VARINA	DLOg1	DLOr11	53
ABERDEEN	DURHAM South	DLOg1	DLOr8	66
ABERDEEN	RALEIGH West	DLOg1	DLOr21	66
ABERDEEN	GREENSBORO West	DLOg1	DLOr14	68
ABERDEEN	GREENSBORO East	DLOg1	DLOr13	68
ABERDEEN	DURHAM East	DLOg1	DLOr7	70
ABERDEEN	WHITEVILLE	DLOg1	DLOr23	72
ABERDEEN	CLAYTON	DLOg1	DLOr6	75
ABERDEEN	RALEIGH North	DLOg1	DLOr20	76
ABERDEEN	MONROE	DLOg1	DLOr17	78
ABERDEEN	WINSTON-SALEM South	DLOg1	DLOr27	86
ABERDEEN	WINSTON-SALEM North	DLOg1	DLOr26	88
ABERDEEN	CHARLOTTE East	DLOg1	DLOr2	88
ABERDEEN	CHARLOTTE North	DLOg1	DLOr3	91
ABERDEEN	OXFORD	DLOg1	DLOr18	97
ABERDEEN	CHARLOTTE South	DLOg1	DLOr4	99
ABERDEEN	CHARLOTTE West	DLOg1	DLOr5	101
ABERDEEN	YADKINVILLE	DLOg1	DLOr28	107
ABERDEEN	HENDERSON	DLOg1	DLOr15	108
ABERDEEN	WILMINGTON South	DLOg1	DLOr25	120
ABERDEEN	GASTONIA	DLOg1	DLOr12	122
ABERDEEN	WILMINGTON North	DLOg1	DLOr24	124
ABERDEEN	SPRUCE PINE	DLOg1	DLOr22	186
ABERDEEN	EDENTON	DLOg1	DLOr9	202
ABERDEEN	HENDERSONVILLE	DLOg1	DLOr16	208
ABERDEEN	ASHEVILLE	DLOg1	DLOr1	219
AHOSKIE	EDENTON	DLOg2	DLOr9	31
AHOSKIE	HENDERSON	DLOg2	DLOr15	93
AHOSKIE	CLAYTON	DLOg2	DLOr6	108
AHOSKIE	OXFORD	DLOg2	DLOr18	109
AHOSKIE	RALEIGH North	DLOg2	DLOr20	111
AHOSKIE	RALEIGH West	DLOg2	DLOr21	120
AHOSKIE	DURHAM East	DLOg2	DLOr7	127
AHOSKIE	FUQUAY-VARINA	DLOg2	DLOr11	130
AHOSKIE	DURHAM South	DLOg2	DLOr8	132
AHOSKIE	WILMINGTON North	DLOg2	DLOr24	148
AHOSKIE	FAYETTEVILLE West	DLOg2	DLOr10	154
AHOSKIE	WILMINGTON South	DLOg2	DLOr25	155

Figure C-1. GAMS Screenshot for the Optimization Model

C:\Users\badiv\OneDrive - Fayetteville State University\NCDOT\NCDMVProject\data\NCDMVOptimizationLP.gms

NCDMVOptimizationLP.gms

```
DLOg81.DLOr22        281
DLOg81.DLOr16        311
DLOg81.DLOr1         319
/;

VARIABLES
z objective function value

p(j) hourly number of RealIDs issued in office j
x(i,j) number of DMV clerks received from physical location i to j
o(j) number of overtime hours work in office j
m(j) if office j is supported by by mobile DMV unit nearby
;
Positive variable  p(j) ;
integer variable x(i,j);
binary variable m(j), o(j);


EQUATIONS
OBJECTIVE  minimize the cost of DLE transfer+overtime + mobile support
c0(j)      office j cannot get more than 5 DLEs
c1(j)      arrival rate should be equal to
c2(i)      total outgoing DLEs cannot exceed existing number
c3(j)      hourly RealId transactions completed in office j
c4(j)      daily RealID transactions should be greater than the daily demand
c5(j)      service rate > arrival rate
c6         upper bound on the number of mobile units
c7(j)
;

OBJECTIVE  .. z=e= sum((i,j), dist(i,j)*x(i,j)+ 20*m(j) + 50*o(j))
;

c0(j).. sum(i, x(i,j))=l= 5;
c1(j).. sum(i, x(i,j))=g= (l(j)-s(j))/k(j);
c2(i).. sum(j, x(i,j))=l= DLEi(i);
c3(j).. p(j)=e= (DLE(j) + sum(i, x(i,j)))*k(j) + m(j)*6;
c4(j).. p(j)*8 + 4*DLE(j)*k(j)*o(j)=g= d(j);
c5(j).. p(j) =g=l(j);
c6   ..sum(j, m(j)) =l=9;
c7(j)..  o(j) +m(j) =e=1;;

model aggpl /all/;
solve aggpl minimizing z using mip;
display  x.l, o.l, m.l, p.l;
```

Figure C-2. NEOS Solver Report for the Optimization Model

```
*************************************************************

   NEOS Server Version 5.0

   Disclaimer:

   This information is provided without any express or
   implied warranty. In particular, there is no warranty
   of any kind concerning the fitness of this
   information  for any particular purpose.
*************************************************************
Job 8340531 has finished.
Executed on prod-exec-2.neos-server.org
□GAMS 31.1.1  r4b06116 Released May 16, 2020 LEX-LEG x86 64bit/Linux 06/26/20 04:05:13 Page 1
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
C o m p i l a t i o n



COMPILATION TIME     =        0.004 SECONDS      3 MB  31.1.1 r4b06116 LEX-LEG
□GAMS 31.1.1  r4b06116 Released May 16, 2020 LEX-LEG x86 64bit/Linux 06/26/20 04:05:13 Page 2
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Model Analysis      SOLVE aggpl Using MIP From line 2601


****
****  2268 Integer +INF Bounds have been reset to 100 (see Option IntVarUp)
****
□GAMS 31.1.1  r4b06116 Released May 16, 2020 LEX-LEG x86 64bit/Linux 06/26/20 04:05:13 Page 3
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Model Statistics    SOLVE aggpl Using MIP From line 2601


MODEL STATISTICS

BLOCKS OF EQUATIONS           9     SINGLE EQUATIONS          251
BLOCKS OF VARIABLES           5     SINGLE VARIABLES        2,353
NON ZERO ELEMENTS        11,621     DISCRETE VARIABLES      2,324


GENERATION TIME      =        0.009 SECONDS      5 MB  31.1.1 r4b06116 LEX-LEG


EXECUTION TIME       =        0.009 SECONDS      5 MB  31.1.1 r4b06116 LEX-LEG
□GAMS 31.1.1  r4b06116 Released May 16, 2020 LEX-LEG x86 64bit/Linux 06/26/20 04:05:13 Page 4
G e n e r a l   A l g e b r a i c   M o d e l i n g   S y s t e m
Solution Report     SOLVE aggpl Using MIP From line 2601


               S O L V E      S U M M A R Y

     MODEL   aggpl               OBJECTIVE  z
     TYPE    MIP                 DIRECTION  MINIMIZE
     SOLVER  CPLEX               FROM LINE  2601
```