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Partial Interchanges in New Jersey: Data Development and Evaluation

FINAL REPORT

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16. Abstract

The interstate system was constructed with the intent to increase the connectivity of our nation. However, over several decades of construction, a number of links (moves) are still not completed. The Federal Highway Administration (FHWA) has a vested interest in ensuring the viability and efficient operation of interstate highway facilities, and to promote the completion of these missing moves. Recognizing the importance of this issue and the role they have in developing and managing the statewide transportation system in New Jersey, the New Jersey Department of Transportation (NJDOT) and FHWA initiated a statewide study of partial interchanges, including the development of a systematic approach to evaluating the missing connections and recommendations for upgrading partial interchanges where such investment is warranted. In keeping with NJDOT's statewide objective of maintaining, enhancing, and implementing tools for analyzing transportation system performance and implementing an effective asset management process, NJDOT initiated this project to develop a partial interchange evaluation methodology. The results of this evaluation are meant to provide guidance to constituents in identifying priority projects for future review and possible inclusion into the capital program. This study screened all the partial interchanges in New Jersey and identified ten partial interchanges which underwent further modeling. Out of 10 interchanges modeled, six interchanges were identified as high priority for a full planning/scoping study that would be required for each project prior to making any final determination.

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1 EXECUTIVE SUMMARY

The interstate system was constructed with the intent to increase the connectivity of our nation. However, over several decades of construction, a number of links (moves) are still not completed. Recognizing the importance of completing these links in New Jersey, the New Jersey Department of Transportation (NJDOT) and the Federal Highway Administration initiated a statewide project to study partial interchanges in order to develop a systematic approach to evaluate the missing connections, and make recommendations for upgrading partial interchanges where such investment is warranted.

This study screened all of the partial interchanges in New Jersey on the Interstate Highway system, and identified ten partial interchanges which underwent further modeling (identifying a benefit to cost ratio for each one). Out of the ten interchanges modeled, six interchanges were identified as high priority for a full planning/scoping study of each that would be required prior to making any final determinations.

Partial Interchange

Partial interchanges can be defined as an interchange that is missing at least one of the movements between the two interchanging highways. This consideration includes both directions on both interchanging highways. Partial Interchanges have adverse impacts on local and regional access and mobility such as:

- Compromised safety due to lack of direct access to an interstate highway facility
- Physical and operational stress of the local street network in the vicinity of a partial interchange
- Local and regional congestion and excessive overall regional vehicle miles traveled (VMT), creating unnecessary pressure on limited highway capacity
- Negative environmental impacts of excessive travel and congestion

In general, there are two major constraints that factor into the construction of a partial—as opposed to a completed—interchange:

1. **Physical Constraints**: when close proximity of another interchange is deemed sufficient or there is a lack of space to safely build all of the needed ramps
2. **Cost Constraints:** when the cost of building the ramps cannot be justified by the traffic volume seeking to make those moves

Along with the NJDOT, FHWA proposed a statewide study of partial interchanges, including the development of a systematic approach to evaluate missing connections and recommendations. The main objectives of this research study were:

1. Identify, catalog, and collect data about partial interchanges in New Jersey
2. Implement a methodology to select the critical/most viable interchanges to be improved
3. Use Geographic Information System (GIS) data and planning models as decision-support tools
4. Develop a methodology for quantitative evaluation of upgrading partial interchanges

To meet this challenge, the team developed an evaluation methodology that includes:

- Screening analysis of the inventoried partial interchanges
- Sensitivity analysis of the partial interchanges resulting from the screening analysis
- A benefit cost analysis of the screened partial interchanges

The resultant final list, or prioritized list of partial interchanges are not prescriptive, but are meant to provide guidance to constituents in identifying priority locations for further analysis and possible inclusion as problem statements into NJDOT's project development process. Partial interchanges that scored higher in the screening analysis are considered potential candidate interchanges for future improvements. Once a decision is made to investigate interchange locations for project development, NJDOT's interagency Congestion Management Committee would take the lead as part of the congestion relief problem statement development process.

STEP 1: SCREENING ANALYSIS

A catalog of partial interchanges in New Jersey identified a total of 105 partial interchanges on the interstate highway system in New Jersey, representing nearly half of all interstate interchanges.

Using the regional travel demand forecasting models (i.e., NJRTM-E and DVRPC Travel demand model), partial interchanges in need were narrowed down and prioritized for further studies. The screening methodology consists of two phases:

- **Phase 1: Hard Constraint Evaluation**

In this phase, partial interchanges where construction of missing ramps would involve major demolition of the built environment and/or major ROW acquisitions, or hampered by natural barriers such as rivers, challenging terrain), and/or would cause disturbance of environmentally sensitive areas, including agricultural land, barren land, forests, water, and wetlands were screened out.

All partial interchanges that pass the **Phase 1 Screening Process** were examined again in Phase 2.

— **Phase 2: Score-Based Evaluation**

In this phase, partial interchanges are scored and prioritized. The higher the total score, the higher the ranking. The scores are calculated based on the following four criteria:

i. **Traffic Congestion Score:** Calculated with the vehicle capacity ratio (V/C), travel time indices (TTI) and roadway congestion indices (RCI) data obtained from the New Jersey Congestion Management System (NJCMS)
ii. **Functional Class of the Cross Road:** The higher the functional class, the higher the score.
iii. **Traffic Safety**: The traffic safety score is an average of the crash rate score and the crash severity rate score
iv. **Freight Trip Generators:** Assessed freight activities based on truck origin and destination analysis, in the vicinity of partial interchanges

In all, a total of 57 partial interchanges were analyzed and scored**.** The partial interchanges that received higher scores (or ranked higher by the total score) should be considered to have a higher priority in future improvements.

STEP 2: SCREENING SENSITIVITY ANALYSIS

Sensitivity analysis was conducted based on varying criteria weights on the **57 partial interchanges resulting from the screening analysis** (refer to Table 4 of the full report) to evaluate whether the top 20 interchanges would remain among the top 20 if some fundamental assumptions are changed.

The results of the sensitivity analysis:

i. 18 interchanges consistently ranked among the top 20 in all weighting alternatives
ii. Two interchanges (I-676 and Route 537, Interchange 5 and I-280 and NJ 21, Interchange 15) did not rank in the top 20 in at least one of the three sensitivity analysis alternatives
iii. Another two interchanges (I-80 and US 46, Interchange 38 and I-78/N.J. Turnpike Extension and Hudson County 612, Interchange 14C) failed to ranked in the top 20 after applying the alternative criteria weights, but ranked in the top 20 in the other alternatives

STEP 3: CALCULATING THE BENEFIT/COST ANAYSIS

Modeling the Benefits of Interchange Improvements

To appraise the viability of improving the interchanges in the ranked list, the team developed a methodology to assess the impact of improving partial interchange movements; similar to general benefit/cost analysis methods employed in evaluating the effect of transportation improvements. The methodology compares the costs of constructing missing on- or off-ramps to the estimated benefits (or savings) in various user cost categories. Using the regional travel demand a "what-if" analysis was performed to estimate the impact of the partial interchange upgrades on the transportation network. The implementation of this methodology was conducted with the following steps:

Step 1: Traffic assignment for the baseline scenario: Perform the traffic assignment with the existing interchange design and record VMT and VHT for each link in the model network

Step 2: Identify the missing movements and modify the network by adding links that would facilitate these movements: For each analyzed interchange, all missing movements are added while assuming the improvement would entail a full interchange upgrade

Step 3: Traffic assignment for the upgrade (built) scenario: Perform the traffic assignment in the network that includes the links facilitating missing movements

Step 4: Calculate the benefit of the upgrade as a difference between the system costs for the baseline and upgrade scenarios: Using the "before" (baseline, or "no-build") and "after" ("built") scenario results of travel demand models, the benefits of the interchange improvement project are estimated as reduction in various user costs between the two scenarios.

The calculation of road users' costs for each cost category is as follows:

i. **Calculation of travel time cost savings:** calculated as a difference between the total travel time in the baseline scenario and the total travel time in the upgrade scenario (including both passenger cost and truck operating cost)

ii. **Calculation of fuel consumption savings:** Vehicle fuel consumption savings are calculated as a function of vehicle flow parameters derived from the results of VMT

iii. **Calculation of vehicle emissions savings:** The emission rates and unit costs for HC, CO, and NOx (dependent on vehicle type and speed) were obtained from IDAS and used to calculate the monetary value of savings in vehicle emissions as a difference between the existing partial interchange and the upgraded interchange scenarios

Benefit/Cost Analysis Calculation Methodology

The merit of each interchange improvement is determined based on the **benefit/cost (B/C) ratio** associated with the improvement. In this context, the "**Cost"** refers to the construction cost of each improvement. The "**Benefit"** refers to the difference between the road users' cost if the improvement is not implemented ("No-build" scenario) and road users' cost with full implementation of the improvement ("Build" scenario).

The B/C ratio is calculated with respect to the present value or annualized value of the total benefits and costs. In this study, the corresponding benefits and costs where "**No-build**" or "**Baseline**" scenario assumes that the interchange **will not be upgraded**. "**Build**" scenario assumes that the interchange **will be upgraded** by completing all "missing movements".

How to apply the Study Results?

The results of the study are based on the evaluation methodology developed in collaboration with the NJDOT and Metropolitan Planning Organizations (MPOs). The results are meant to provide guidance to constituents in identifying priority locations for further analysis and possible inclusion as problem statements into NJDOT's project development process. Any accepted problem statement would undergo a full planning/scoping study as part of the Concept Development phase, prior to which would need FHWA approval before moving into the design phase.

These results are not "all inclusive" and do not take into account non-quantifiable benefits. Any improvement that increases access has an inherent quality of life benefit (e.g., improves access to hospitals, parks and recreation facilities, employment centers, etc.); however, this benefit may only have quantifiable VMT benefits for a relatively small population (such as a local community), and therefore, when considering the larger regional network, it may not result in an overall favorable B/C ratio. This does not mean that the project should not be considered; but, that constituents should take into account non-quantifiable factors when considering what projects to move forward.

The evaluated interchange upgrade projects with a positive B/C analysis are labeled as "high priority". The research team did not feel it was appropriate to rank any of the analyzed interchange upgrades as low priority or not cost-effective, even with negative calculated B/C ratios. Hence, those with a negative B/C ratio are labeled as "medium priority." The prioritizations presented in Table 18 provide a starting point for the NJDOT and MPOs to move projects forward.

2 BACKGROUND

Highway interchanges are critical to providing an adequate level of service, mobility, and safety. Well-placed interchanges connect highways with limited access and other roadways in a highway network, keeping an optimal flow and exchange of traffic in complex transportation systems like the one in New Jersey. Throughout the state, there are several facilities with limited access, including the interstate highway system; those under highway authority jurisdiction, such as the Garden State Parkway, New Jersey Turnpike, Atlantic City Expressway, Palisades Interstate Parkway in New Jersey; and sections of other state highways; and a few instances on county-level arterials.

While highway interchanges provide connectivity between underlying highway facilities for all directions, this may not be the case on some interchanges. There are interchanges that are missing certain moves (e.g., I-80 EB to NJ-46 in Netcong, NJ, or NJ-21 NB to I-280 WB in Newark, NJ); these are referred to as “partial interchanges.” In general, there are two major constraints that factor into the construction of a partial—as opposed to a completed—interchange:

1. **Physical constraints**: when close proximity of another interchange is deemed sufficient or there is a lack of space to safely build all the ramps

2. **Cost constraints**: when the cost of building the ramps cannot be justified by the traffic volume seeking to make those moves

However, as new residential and non-residential developments are built—along with changes in land use and increases in travel demand—it becomes necessary to revisit the design of existing partial interchanges serving local and regional traffic, and perhaps even consider building new interchanges.

Besides reducing local and regional mobility, adverse impacts of partial interchanges include:

- Compromised safety due to lack of direct access to an interstate highway facility, inducing excessive use of local streets, or, worse, driveways and parking lots as access alternatives

- Physical and operational stress of the local street network in the vicinity of a partial interchange

- Local and regional congestion and excessive overall regional vehicle miles traveled (VMT), creating unnecessary pressure on limited highway capacity
- Negative environmental impacts of excessive travel and congestion, including increased fuel consumption and air quality impacts

The Federal Highway Administration (FHWA) has a vested interest in ensuring the viability and efficient operation of interstate highway facilities. Along with the New Jersey Department of Transportation (NJDOT), FHWA proposed a statewide study of partial interchanges, including the development of a systematic approach to evaluate missing connections and recommend partial interchange upgrades where such investments are warranted.

The NJDOT Bureau of Transportation Data Development (BTDD) initiated the development and implementation of the Partial Interchange Evaluation Protocol to adhere to its statewide objective of maintaining, enhancing, and implementing tools that optimize transportation system performance. The implementation of the protocol was complemented by the Interactive Interchange Evaluation Tool, a user-friendly management information and decision-support system that facilitates an effective statewide analysis of partial interchanges. This system provides information about partial interchanges—including performance indicators—that can identify and prioritize transportation investment in partial interchange improvements. The system also establishes a permanent depository for information and data attributes about partial interchanges.

3 OBJECTIVES

The objectives of this research study are as follow:

1. Identify, catalog, and collect data about partial interchanges in New Jersey.
2. Implement the methodology to select the critical/most viable interchanges to be improved.
3. Use Geographic Information System (GIS) data and planning models as decision-support tools.
4. Develop a methodology for quantitative evaluation of upgrading partial interchanges.

4 METHODOLOGY

4.1 Introduction

A sound evaluation methodology was developed to address the study objectives. This methodology includes a partial interchange inventory, a screening analysis, and a benefit/cost analysis. Outputs from these models provide enough information to NJDOT and MPOs to identify and prioritize partial interchanges for detailed operational analysis, design, and engineering of improvement projects.

To identify and catalog the number of partial interchanges in New Jersey, the methodology starts with an inventory of highway connections. A total of 105 partial interchanges were identified in this task as a result.

After conducting the inventory, a screening analysis was performed to prioritize partial interchanges in need using regional travel demand forecasting models (i.e., NJRTM-E and DVRPC Travel demand model). The screening was done in two phases: hard constraint evaluation and score-based evaluation.

Next, a model for assessing the impact of improving partial interchanges' traffic movements was developed using general a cost/benefit analysis method. It compares the costs of constructing missing on- or off-ramps to the estimated benefits of savings in various user-cost categories like mobility, vehicle emission, fuel consumption, and safety. The source of data for this assessment is achieved from the travel demand forecasting model (i.e., NJRTM-E or DVRPC Travel demand model) that estimates the changes in VMT and vehicle hours travelled (VHT) on each link of the transportation network.

4.2 Inventory of Partial Interchanges in New Jersey

The NJDOT and FHWA identified 105 partial interchanges on the interstate highway system in New Jersey, which represents nearly half of all interstate interchanges, making New Jersey a state with one of the highest levels of nonstandard interstate interchanges. In this task, the research team conducted an inventory of all the partial interchanges in New Jersey using available resources, and developed a catalog of these interchanges while acquiring and integrating the tools needed to prioritize those most needing improvement.

4.2.1 Definition of Partial Interchanges

Partial interchange can be defined as an interchange that is missing at least one of the movements between the two interchanging highways. This consideration includes both directions on both interchanging highways. If it is necessary to make a U-turn on a cross road to complete a missing move, either at an intersection or a jug handle (i.e., a progressive movement is not possible), this cannot be considered a complete interchange.

4.2.2 Determination Criteria and Inventory Database

The team determined that two (or more) partial interchanges that complement each other's movements can be considered a functionally single (complete) interchange, if:

- they are on the same main highway, and
- the distance between the geometric intersections of the centerlines of the main highway and the corresponding cross roads (highways) is within one mile.

These criteria were used to identify and label partial interchanges in the partial interchange inventory database (See Figure 1), as shown on the website: http://telus-national.org/PartialInterchanges/map.asp.

The inventory database was developed using GIS layers, straight line diagrams (SLD), aerial imagery, site visits, and other available management information system (MIS) tools to identify the interchanges that do not allow for all connecting moves. Once the locations of all partial interchanges were identified, the regional network in the travel demand forecasting models—including the North Jersey Regional Transportation Model-Enhanced (NJRTM-E) and DVRPC Travel Demand Model—was used to ensure all the existing moves at the interchanges were coded correctly. The information in these models and data management systems helped the research team identify the partial interchanges that warrant an improvement based on various traffic performance measures.

Through the inventory, it was found that some interchange determinations deviate slightly from the criteria mentioned above; in these instances, transportation engineering judgment was used. To provide the determination rationale in such cases, another field was added in the summary table for each interchanges where comments were provided. For example, if two (or more) partial interchanges complement each other to a complete interchange, they should all be labeled as complete interchanges, with respective notes (e.g., "missing moves in this interchange are facilitated at interchange No. 14 (0.4 miles to the east).") in this data field.

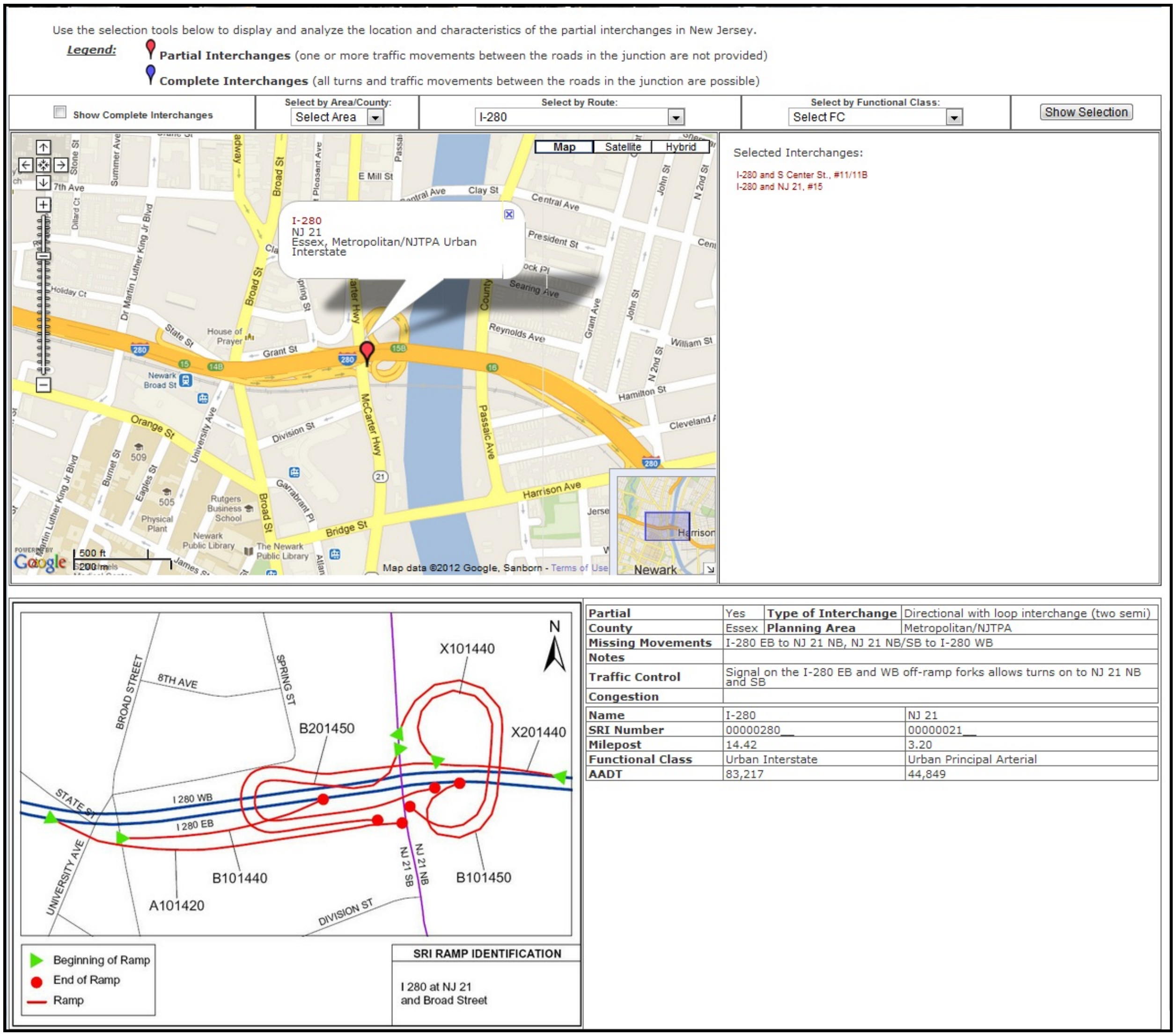

Figure 1: Snapshot of the Partial Interchange Inventory Database

Source: http://telus-national.org/PartialInterchanges/map.asp

4.3 Screening Analysis

The purpose of the developed screening methodology is to narrow down the number of partial interchanges that should be studied in greater detail using the regional travel demand forecasting model (i.e., NJRTM). The screening was based on a number of criteria aimed at identifying the relative “importance” and potential impact of improvements at each evaluated partial interchange. The screening methodology consists of two phases:

- Phase 1: hard constraint evaluation
- Phase 2: score-based evaluation

4.3.1 Screening Methodology

The proposed two-phase screening methodology is illustrated in Figure 2. In phase 1, the screening process begins by checking for any environmental, land use, and/or right-of-way constraints for upgrading a partial interchange. This will screen out those partial interchanges where construction of missing ramps would involve major demolition of built environment and/or major ROW acquisition investment, is hampered by natural barriers (e.g., rivers, challenging terrain), and/or would cause disturbance of environmentally sensitive areas, including agricultural land, barren land, forests, water, and wetlands.

To analyze land use and right-of-way limitations, the land use/land cover data was obtained from the New Jersey Department of Environmental Protection (NJDEP) and used in conjunction with aerial photography to verify any physical or environmental barriers that limit improvements of partial interchanges. If a partial interchange passes the environmental/land use/ROW constraint test, then the geometric design requirements for the improvements were evaluated based on the FHWA and NJDOT highway design standards. This constraint disqualified any interchange improvement that does not meet the standards and requirements of interchange spacing with respect to acceleration/deceleration lanes and ramp lengths.

All partial interchanges that pass the Phase 1 screening were examined again in Phase 2 of the screening process. In Phase 2, partial interchanges were scored and then prioritized based on the total scores. The higher the total score, the higher the ranking. In this phase, each partial interchange was evaluated and scores were given based on four criteria: congestion, functional class of the cross road, traffic safety, and freight trip generators. The following discusses each criterion in detail.

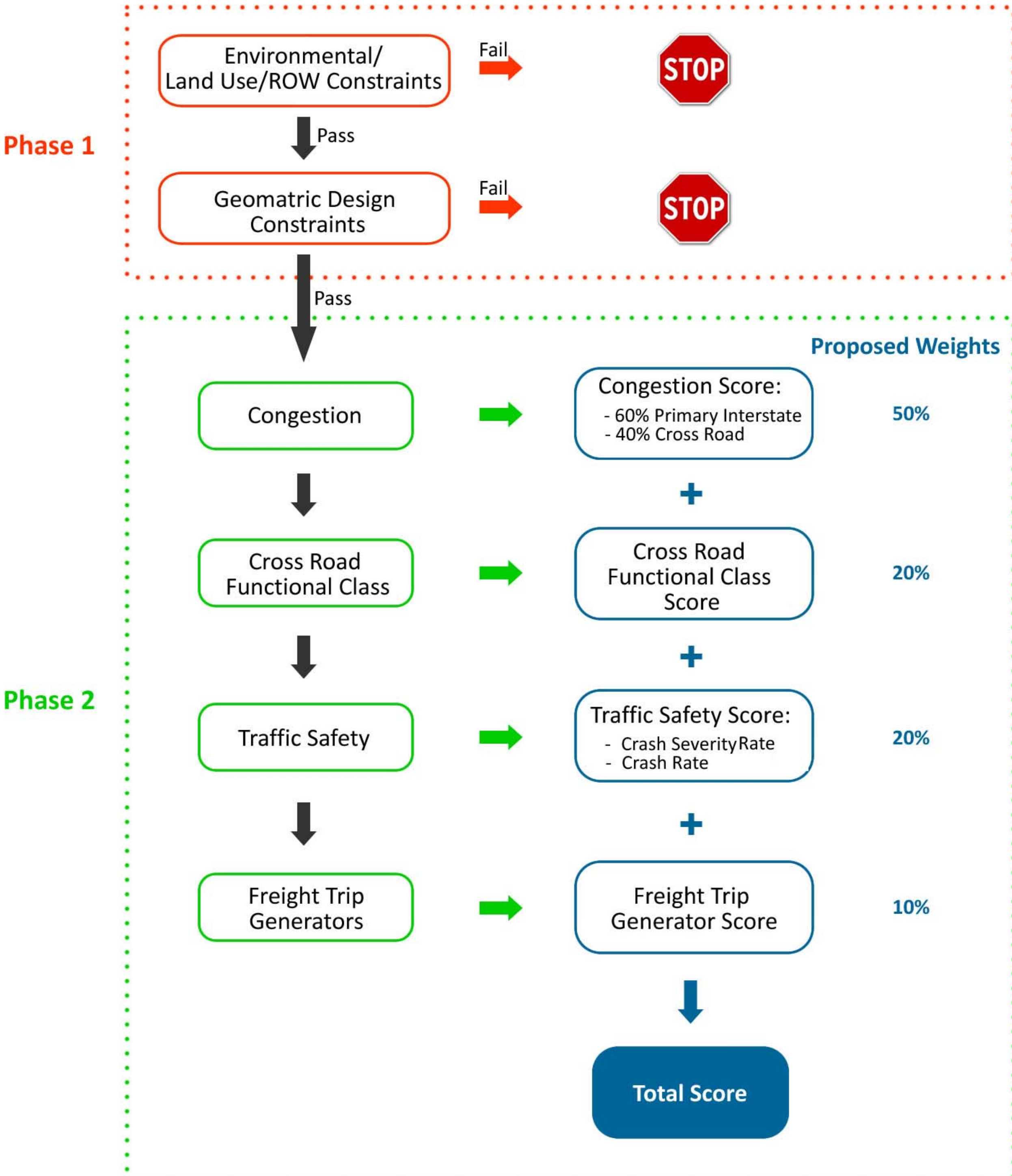

Figure 2. Schematic Presentation of the Proposed Two-phase Partial Interchange Screening Methodology

Traffic Congestion

The V/C ratios, travel time indices (TTI), and roadway congestion indices (RCI) were obtained from the New Jersey Congestion Management System (NJCMS) and were used to quantify traffic congestion on both primary (interstate) highways and cross roads. The score was given to each highway based on the congestion level. The higher the congestion level, the higher the score. The congestion levels for partial interchanges were calculated as weighted averages of congestion measures on primary and secondary highways (60:40 ratio in favor of the primary highway). Alternatively, the congestion measures for all roads in the vicinity of the partial interchange were calculated and analyzed (e.g., all roads in a 0.5 –1.0 mile radius around the interchange). In this case, congestion score was calculated as an average of congestion performance measures on different roadways weighted by the roadway functional class (interstate highways/freeways having the highest weight, followed by major arterials, minor arterials, and collectors). The proposed weight of the congestion score is 50 percent.

Cross Road Functional Class

Assuming the primary road is an interstate highway, the functional class of the cross road was determined, and the score was given to the partial interchange based on the road classification. The higher the functional class, the higher the score. The proposed weight of the cross road functional class score is 20 percent.

Traffic Safety

Traffic safety analysis was performed on an area defined by an interchange milepost (e.g., milepost of the geometric intersection of the highway centerlines) and the roadway network surrounding this location in a half-mile radius. Crash rate and crash severity rate were estimated for the defined area. To calculate crash rates and severity rates, average annual daily traffic (AADT) should be known for all analyzed roadways. Since AADT is not readily available for all roadways in the state of New Jersey, it had to be estimated as a first step in this analysis. AADT was estimated considering the total VMT and total mileage of roadways for each roadway functional class extracted from NJDOT’s CMS database. The crash and severity rate for a specific roadway functional class was then estimated using the statewide (or countywide) crash data. It is worth noting that crash severity rate shifted the attention toward fatal and injury crashes defined by the weighting system (e.g., fatal crashes have a higher weigh than property damage only [PDO] crashes). Therefore, two safety factors were estimated and presented to users based on the data extracted from the past three consecutive years:

crash rate and **crash severity rate**. The safety score was calculated using the following methodology:

1. Calculate the crash and crash severity rate for all roadways by functional class in a radius of a half-mile around the analyzed interchange
2. Assign higher weights to the primary road and cross road at the interchange, and consider other roadways in the vicinity with the uniform weight
3. Calculate the crash and crash severity rate scores as sums of:

$$\text{Crash rate factor} = \text{sum}\left[(C_{cr} \times 2)(P_{cr} \times 2)\left(\sum_{i=1}^{n}(R_{cri} \times 1)\right)\right] \quad (1)$$

$$\text{Severity rate factor} = \text{sum}\left[(C_{sr} \times 2)(P_{sr} \times 2)\left(\sum_{i=1}^{n}(R_{sri} \times 1)\right)\right] \quad (2)$$

Where: C_{cr} = cross road crash rate
C_{sr} = cross road severity rate
P_{cr} = primary road crash rate
P_{sr} = primary road crash severity rate
R_{cr} = crash rate of all other roadways in a radius of a half-mile
R_{sr} = severity rate of all other roadways in a radius of a half-mile

The score was given to each partial interchange based on two safety factors; the higher the crash and severity rates were, the higher the score. The proposed weight of the traffic safety score is 20 percent.

Freight (Truck) Trip Generators

Trucks generally have greater impact on traffic operations, especially mobility and safety. Trucks also perform much better on higher-level roadways due to better roadway geometry (wider lanes, milder curves, wider turns). For these reasons, freight activity in the vicinity of partial interchanges was assessed to measure the impact of providing full access to freeways at each evaluated partial interchange. Different assessment approaches can be taken with respect to identifying truck activity (summarized in

Table **1**):

- **Truck O-D Trip Table**: The truck O-D trip table from NJDOT's truck model was utilized. Once it was overlaid with the GIS map of New Jersey, a 1-mile-radius circle was drawn around the evaluated partial interchanges to identify freight trip generators as well as to determine freight activity in terms of truck trips (in and out) in the vicinity of partial interchanges.

- **Freight Generator Locator**: The freight locator utility of the IHS Global Insight TRANSEARCH database was utilized to identify major freight generators in the vicinity of partial interchange. The TRANSEARCH database is the exclusive source for U.S. county-level freight movement data by commodity group and mode of transportation.

- **Truck Trip Rates**: The NJDOT statewide truck model's trip production and attraction rates will be utilized to identify freight activity. The rates by industry will be multiplied by the county business pattern for each industry group to estimate the number of truck trips in an area around an evaluated partial interchange. Table 2 displays the typical NJDOT truck model truck trip rates obtained from NCHRP Report 606 titled Forecasting Statewide ToolKit.

Table 1. Freight Activity Assessment: Data Sources and Easiness of Use

Freight Activity Indicator	Geographic Area Coverage	Data Source	Cost	Easiness of Use
Truck O-D trip table	Statewide	NJDOT Truck Model	Free	High
Freight generator locator	North Jersey Transportation Planning Authority (NJTPA)**	IHS Global Insight TRANSEARCH or freight locator databases	Free w/ NJTPA license *	Medium
Truck trip rates	Statewide	NJDOT Truck Model	Free	Low

* Unknown coverage for South Jersey Transportation Planning Organization and Delaware Valley Regional Planning Commission

** NJTPA would have to provide data.

Table 2. Internal Truck Trip Rates (NJDOT Statewide Model)

Variable	Other Models: Phoenix (1991) [a]	Washington D.C.	Vancouver [b]	San Francisco (1993) [c]	Final New Jersey Truck Model
Equations and Coefficients (Heavy Trucks)					
Retail Employment	0.0615	0.0300		0.0001	0.0590
Industrial Employment	0.0833	0.0300	0.0665	0.0293	0.0800
Public Employment	0.0400	0.0200		0.0220	0.0384
Office Employment	0.0053	0.0200	0.1640	0.0220	0.1207
Total Employment				0.0112	
Households	0.0210				0.0202

a. Trucks over 28,000 pounds – attraction rates only.

b. Trucks over 44,000 pounds.

c. Assumed three- and four-axle truck rates are “heavy truck” – production rates only.

Variable	Other Model: Phoenix (1991) [a]	Washington D.C.	Vancouver [b]	San Francisco (1993) [c]	Final New Jersey Truck Model
Equations and Coefficients (Medium Trucks)					
Retail Employment	0.2213	0.1700	0.0212	0.0140	0.1264
Industrial Employment	0.1665	0.1400	0.0212	0.0110	0.0522
Public Employment	0.0100	0.0400	0.0212	0.0460	0.0032
Office Employment	0.0354	0.0100	0.0212	0.0105	0.0202
Total Employment				0.0324	
Households	0.1145	0.0400	0.0041		0.0240

Source: URS Greiner Woodward Clyde, “Statewide Model Truck Trip Table Update Project.” Prepared for New Jersey Department of Transportation, January 1999.

a. Trucks between 8,000 and 28,000 pounds – attraction rates only

b. Trucks between 9,000 and 44,000 pounds

c. Assumed two-axle truck rates are “medium truck” – production rates only

The score was assigned to each partial interchange based on the size of the trip generator and the number of truck trips. The bigger the size and the higher the number of truck trips, the higher the score. The proposed weight of the freight trip generator score is 10 percent.

4.3.2 Screening Results

A total of 57 partial interchanges were analyzed; the locations of each partial interchange are displayed in Figure 3. The interchanges were analyzed and scored with respect to the following five criteria:

1. Congestion
2. Cross Road Functional Class
3. Traffic Safety
4. Truck Activity
5. Land Use (Smart Growth Areas)

The congestion score for each interchange is a function of a weighted average peak-hour volume-to-capacity (V/C) ratio, which is calculated by weighing the V/C ratios on the roads within a half-mile radius around the interchange by the peak-hour VMT on those roads. The score ranged between 1 and 5 as follows:

1 – Weighted average V/C ratio is less than 0.75

2 – Weighted average V/C ratio is between 0.75 and 0.90

3 – Weighted average V/C ratio is between 0.90 and 0.95

4 – Weighted average V/C ratio is between 0.95 and 1.00

5 – Weighted average V/C ratio is equal to or greater than 1.00

The partial interchanges and their congestion scores are shown in Figure 4.

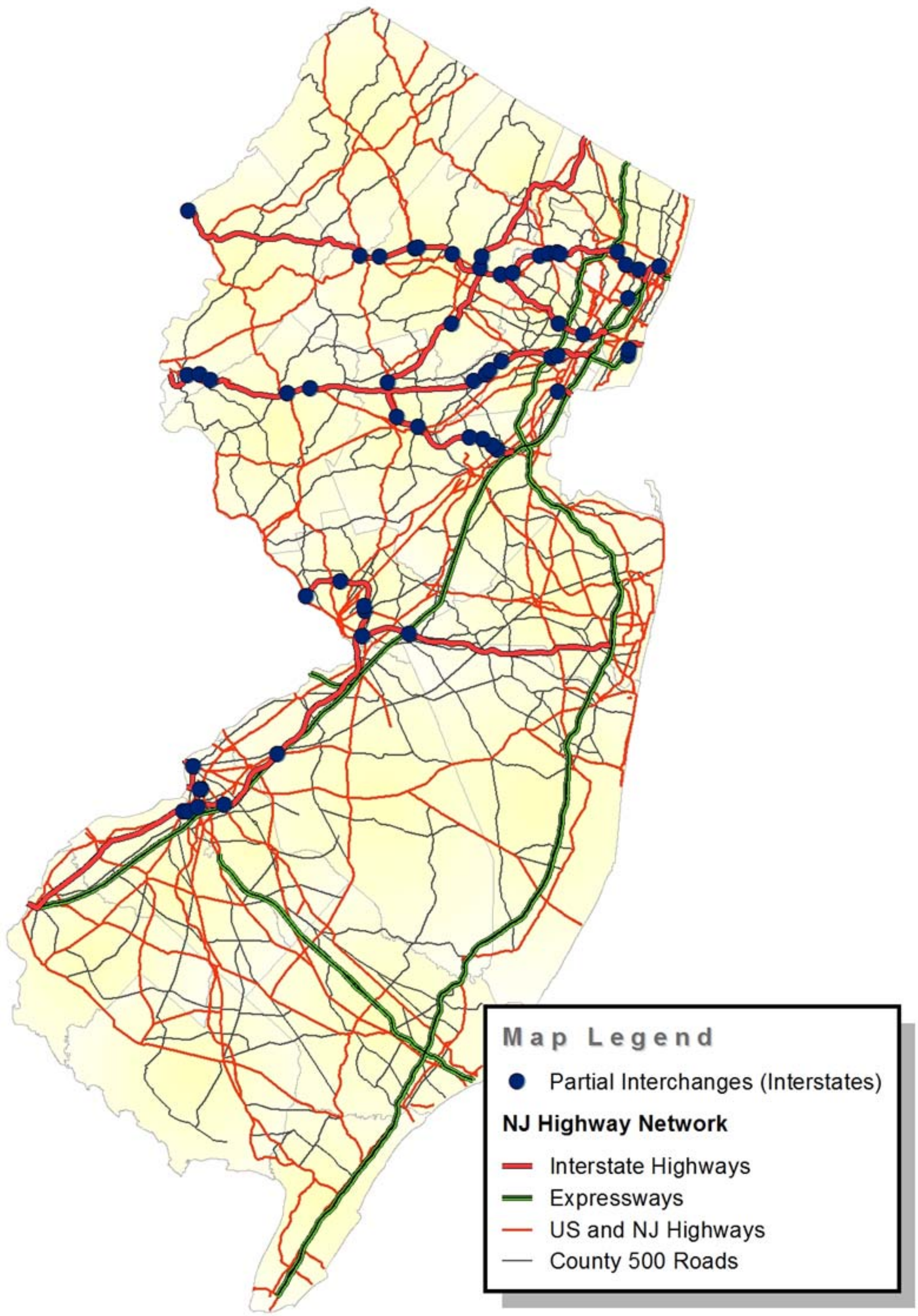

Figure 3. Analyzed Partial Interchanges on the New Jersey Highway Network

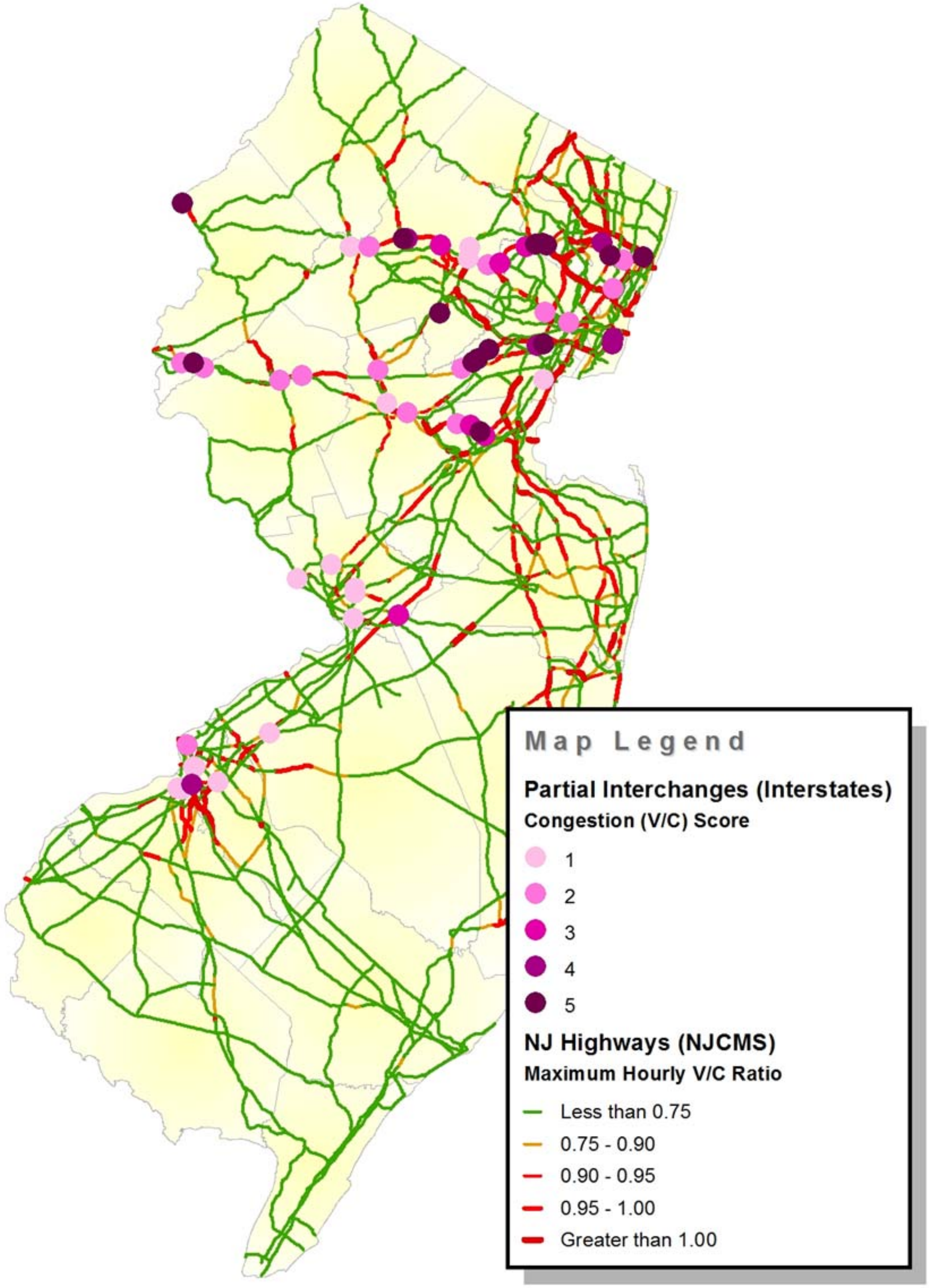

Figure 4. Partial Interchanges and their Congestion Scores

The **traffic safety score** is an average of the crash rate score and the crash severity rate score. The crash rate was calculated as an average number of crashes per million VMT on roadways within a half-mile radius around the interchange. NJDOT crash data for 2005–2009 were used to calculate the rates.

The crash rate score was calculated in an iterative process shown in Figure 5. The interchanges were sorted in ascending order, and those with crash rates less than or equal to the median were given a score of 1. In the second iteration, the interchanges that remained without a score were sorted, and those with crash rates less than or equal to the median were given a score of 2. This procedure was repeated two more times. In the final iteration, all the interchanges with a crash rate less than or equal to the median were assigned a score of 4, and the remaining interchanges were assigned a score of 5.

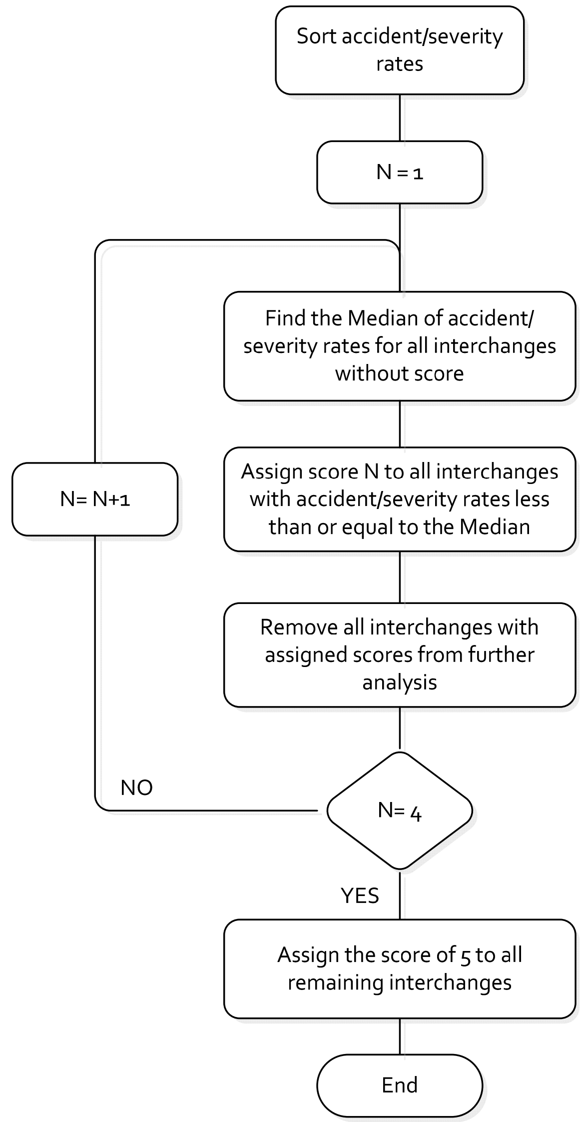

Figure 5. Description of the Method for Calculation of Crash Rate and Crash Severity Rate Scores

The crash severity rate for an interchange was calculated as a number of crash incidents multiplied by the severity index, divided by million VMT on roadways within a half-mile radius of the interchange. The severity index assigns higher weights to fatal and injury crashes relative to property-damage only (PDO) accidents. It equals 5 for fatal crashes, 3 for injury crashes, and 1 for PDO crashes. The crash severity rate was then calculated in the identical fashion as the accident rate score. The results of these traffic safety scores are shown in Figure 6.

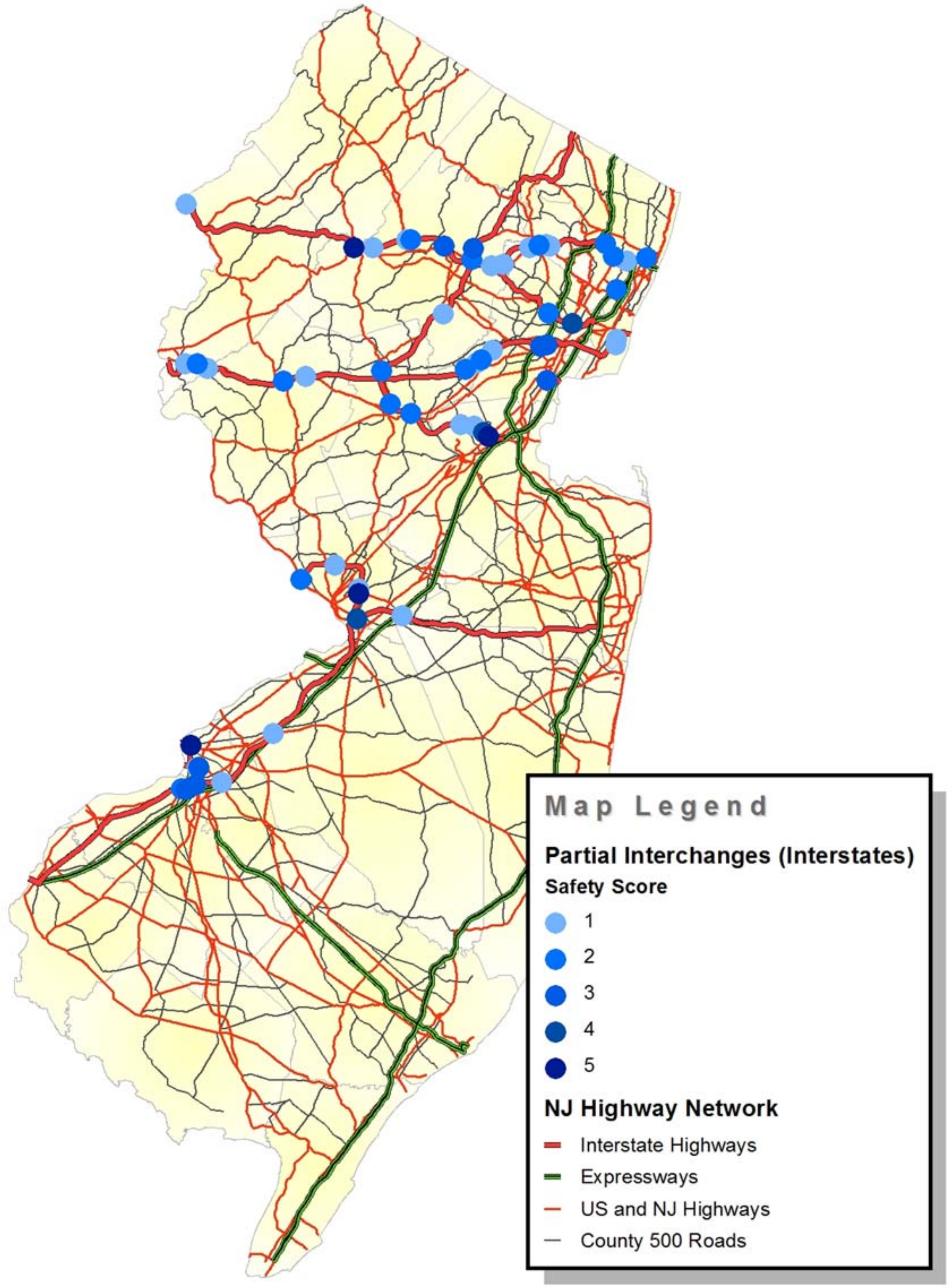

Figure 6. Partial Interchanges and their Safety Scores

Truck activity scores were calculated by overlaying the location of partial interchanges and the New Jersey Statewide Truck Model (NJSTM) zones. The NJSTM provides the total number of daily inbound and outbound truck trips for each zone. The trips with both trip ends (i.e., both origin and destination) within the same zone were excluded from the total because these trips are local, and it is unlikely an interstate highway would be used. Using a GIS tool, a total number of daily truck trips with either an origin or a destination within a half-mile radius of each interchange was calculated. The truck activity score was then determined using the following scoring scale:

1 – Total daily number of truck trips is less than 50 per day

2 – Total daily number of truck trips is between 50 and 100

3 – Total daily number of truck trips is between 100 and 500

4 – Total daily number of truck trips is between 500 and 1,000

5 – Total daily number of truck trips is equal to or greater than 1,000

The partial interchanges with associated truck activity scores are shown in Figure 7.

The **land use (smart growth area) scores** were determined based on a location of each partial interchange relative to New Jersey's smart growth areas as designated in the New Jersey State Development and Redevelopment Plan (SDRP). In collaboration with the MPO stakeholders and NJDOT research panel for this study, it was decided that this should be adopted as a binary score, whereas a score of "1" was assigned to those partial interchanges that were located within a half-mile from a smart growth area. The interchanges that were farther away than a half-mile received a score of "0." The scores were determined using GIS tools to overlay the location of partial interchanges and the smart growth area layer from the SDRP map (downloaded from http://nj.gov/dca/divisions/osg/resources/gis.html). Only five partial interchanges out of 57 received a score of "0," as shown in Figure 8.

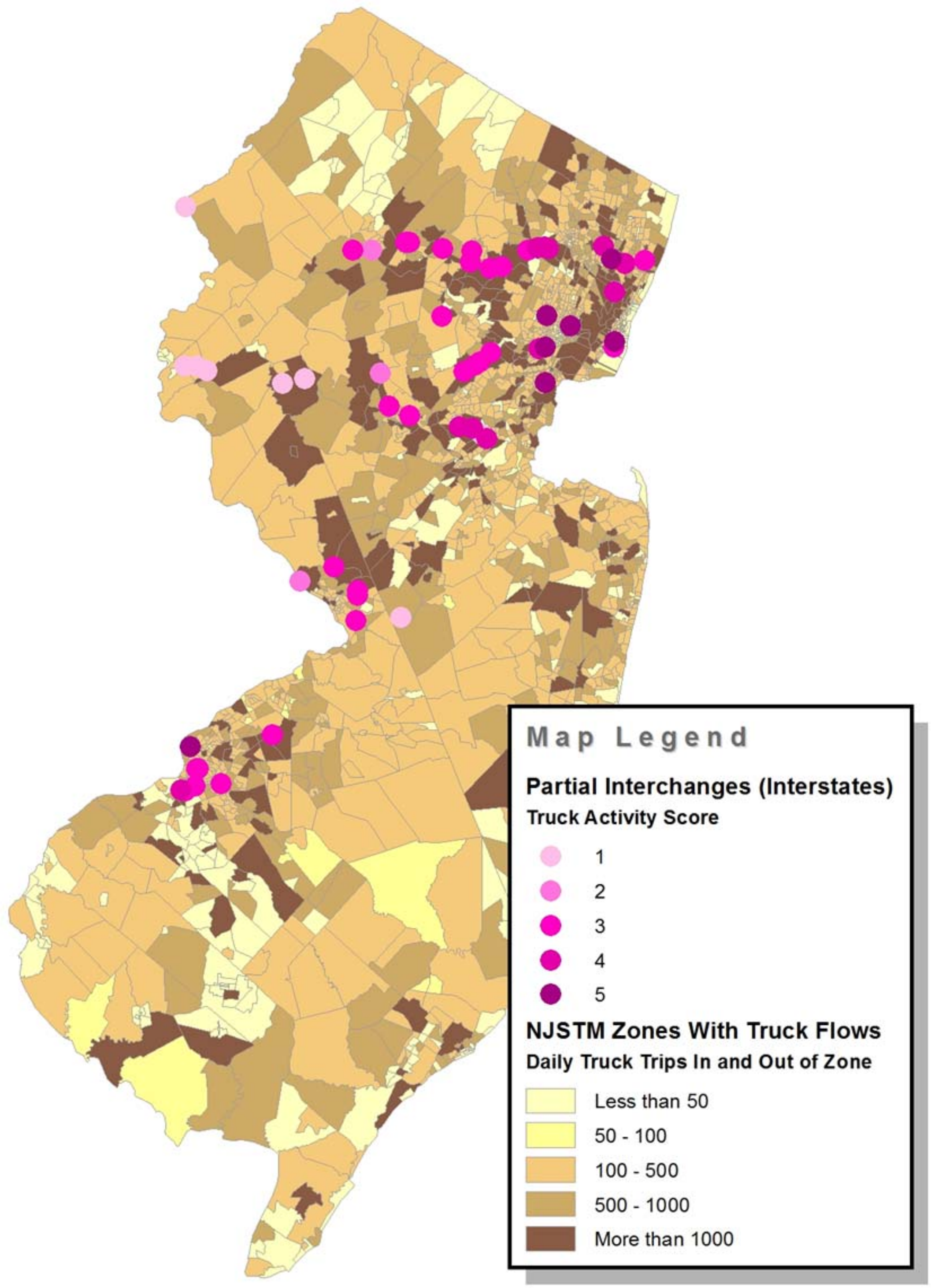

Figure 7. Partial Interchanges and their Truck Activity Score

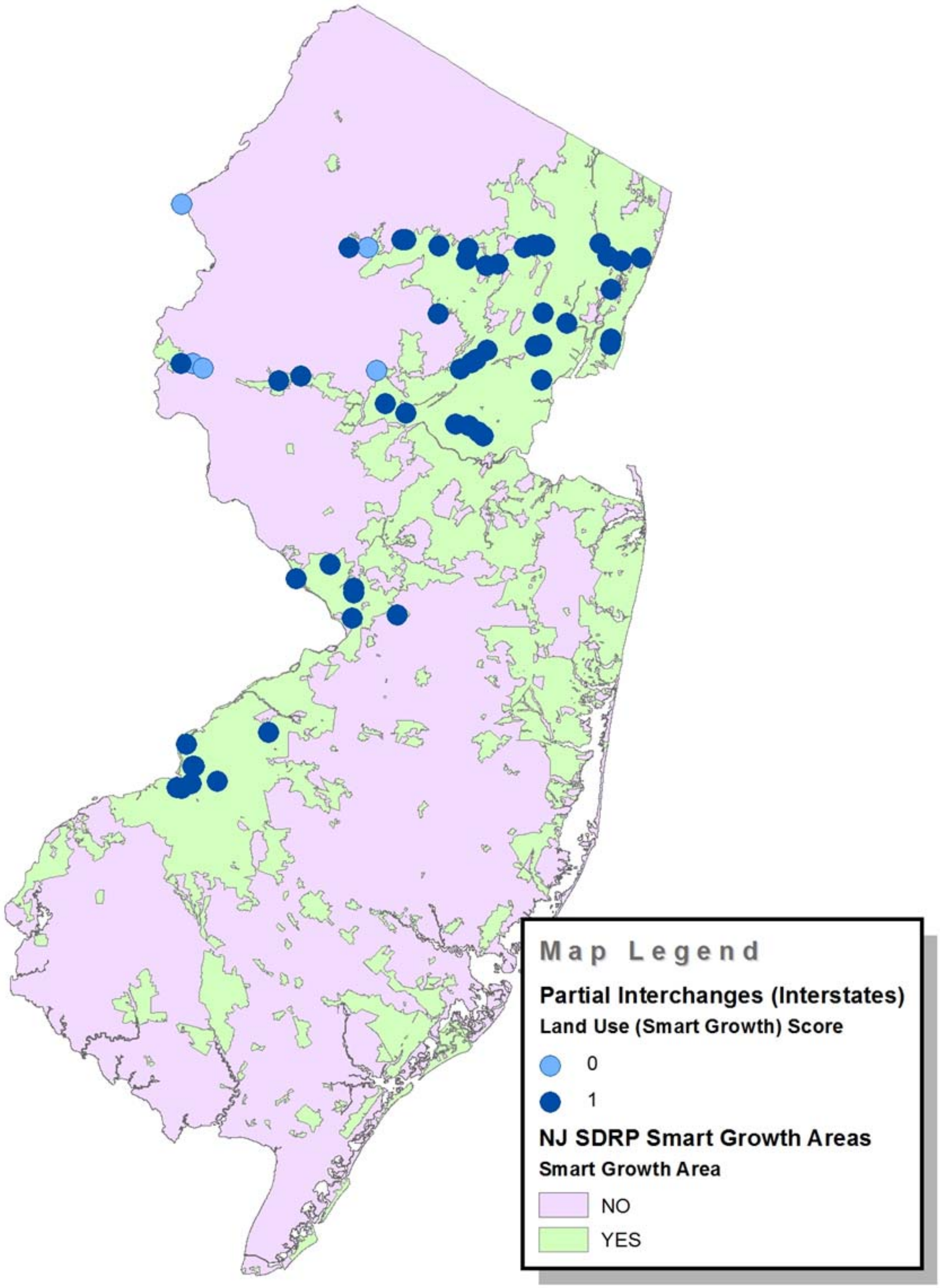

Figure 8. Partial Interchanges and their Land Use (Smart Growth) Score

Finally, the **cross road functional class scores** were determined based on the functional class of the secondary road in the interchange (the primary being an interstate highway). The following scale was used to determine this score:

1 – Urban/rural local roads

2 – Urban/rural collector roads

3 – Urban/rural minor arterials

4 – Urban/rural principal arterials

5 – Urban/rural freeways or expressways

4.3.3 Calculation of Total Scores

The total score for each analyzed partial interchange was calculated as a weighted sum of five individual criteria scores. The maximum possible score is 100. The partial interchanges that received higher scores (or ranked higher by the total score) should be considered to have a higher priority in future improvements.

The following formula was used to calculate the total interchange scores:

$$S_i = 100 \cdot \sum_{j=1}^{5} \frac{s_{i,j}}{m_j} w_j \tag{3}$$

where,

S_i = total score for interchange *i*

$s_{i,j}$ = individual score for criterion *j* for interchange *i*

m_j = maximum individual score for criterion *j*

w_j = relative weight of criterion *j*

The weights (w_j) reflect the relative importance of each criterion in the evaluation. After reviewing several weighting alternatives, and considering the potential impacts an interchange improvement would have with respect to each criterion, the research panel concluded that the criteria weights shown in Table 3 be used in calculating the final interchange scores.

Table 3. Criteria Weights Applied in the Total Interchange Scores

Criterion	Max Score (m_j)	Criteria Weights (w_j)
Congestion (V/C)	5	40%
Safety	5	20%
Truck Activity	5	20%
Land Use (Smart Growth)	1	10%
Cross Road Functional Class	5	10%
TOTAL		**100%**

The calculation of the total score can be illustrated using the following example of the I-78 interchange (No. 54) and Winans Avenue:

Congestion (V/C) Score	= 5
Safety Score	= 3
Truck Activity Score	= 5
Smart Growth Score	= 1
Cross Road Functional Class Score	= 2

The total score for this interchange is calculated as follows:

Congestion (V/C) Score	= 100 x (5/5) x 40%	= 40
Safety Score	= 100 x (3/5) x 20%	= 12
Truck Activity Score	= 100 x (5/5) x 20%	= 20
Smart Growth Score	= 100 x (1/1) x 10%	= 10
Cross Road Functional Class Score	= 100 x (2/5) x 10%	= 4
Total Score		**= 86**

4.3.4 <u>Final Screening Scores and Ranking</u>

The final screening scores and ranking of evaluated partial interchanges are shown in Table 4. The locations of partial interchanges and their ranking are shown in Figure 9.

Table 4. List of Evaluated Partial Interchanges with Ranking and Total Scores

Rank	Interchange	County	Total Score
1	I-78 and Winans Avenue, Interchange 54	Union	86
2	I-80 and NJ 17, Interchange 64	Bergen	86
3	I-80 and NJ 23, Interchange 53	Passaic	82
4	I-78 and Garden State Parkway, Interchange 53	Union	80
5	I-287 and Route 501, Interchange 3	Middlesex	78
6	I-287 and NJ 27, Interchange 2	Middlesex	78
7	I-80 and NJ 62, Interchange 55	Passaic	78
8	I-80 and Passaic County 642, Interchange 54	Passaic	76
9	I-295 and NJ 42, Interchange 26	Camden	76
10	I-78 and CR 527, Interchange 44	Union	74
11	I-95, N.J. Turnpike and Broad Ave (Dana Place), Interchange 71	Bergen	74
12	I-78 and Union County 655, Interchange 43	Union	72
13	I-78/N.J. Turnpike Extension and Hudson County 622, Interchange 14C	Hudson	72
14	I-78 and Route 527, Interchange 45	Union	72
15	I-80 and Morris County 634, Interchange 34	Morris	72
16	I-676 and Route 537, Interchange 5	Camden	70
17	I-80 and NJ 15, Interchange 34	Morris	70
18	I-80 and Bergen County 79 (east of Interchange 62)	Bergen	70
19	I-280 and NJ 21, Interchange 15	Essex	70

Rank	Interchange	County	Total Score
20	I-287 and Harter Road, Interchange 33	Morris	70
21	I-80 and US 46, Interchange 38	Morris	66
22	I-78/N.J. Turnpike Extension and Hudson County 612, Interchange 14C	Hudson	64
23	I-287 and Durham Avenue, Interchange 4	Middlesex	60
24	I-280 and S Center St., Interchange 11/11B	Essex	60
25	I-295 and NJ 33, Interchange 63	Mercer	58
26	I-278 and US 1, Interchange 1	Union	58
27	I-80 and US 46, Interchange 26	Morris	58
28	I-80 and Essex County 613, Interchange 52	Essex	56
29	I-78 and Warren County 637, Interchange 4	Warren	56
30	I-287 and US 22, Interchange 14	Somerset	54
31	I-195 and US 206, Interchange 1	Mercer	54
32	I-80 and Hook Mountain Road, Interchange 48	Morris	54
33	I-95, N.J. Turnpike West Alignment and Continental Arena, Interchange 18W	Bergen	52
34	I-80 and I-280, Interchange 47	Morris	52
35	I-287 and Middlesex County 665, Interchange 6	Middlesex	50
36	I-80 and Old Mine Rd., Interchange 1	Warren	50
37	I-80 and Second Street, Interchange 67	Bergen	50
38	I-78 and Dale Road, Interchange 41	Somerset	48
39	I-295 and NJ 45, Interchange 24	Gloucester	48
40	I-195 and Route 526, Interchange 7	Mercer	48
41	I-76 CONNECTOR and NJ 168, Interchange 35	Camden	48
42	I-295 and NJ 47, Interchange 25	Gloucester	48
43	I-287 and US 202, Interchange 43	Morris	48
44	I-287 and US 202, Interchange 17	Somerset	46

Rank	Interchange	County	Total Score
45	I-287 and US 46, Interchange 42	Morris	46
46	I-78 and NJ 31, Interchange 17	Hunterdon	44
47	I-295 and NJ 38, Interchange 40	Burlington	42
48	I-76 CONNECTOR and US 130, Interchange 35	Camden	42
49	I-287 and US 202, Interchange 22	Somerset	40
50	I-295 and Route 535, Interchange 64	Mercer	40
51	I-95M and Federal City Road, Interchange 5	Mercer	40
52	I-295 and Camden County 669, Interchange 30	Camden	40
53	I-95M and NJ 175, Interchange 1	Mercer	40
54	I-78 and NJ 173, Interchange 3	Warren	40
55	I-78 and Hunterdon County 639, Interchange 20	Hunterdon	38
56	I-80 and Morris County 631, Interchange 28	Morris	34
57	I-78 and Warren County 632, Interchange 6	Warren	28

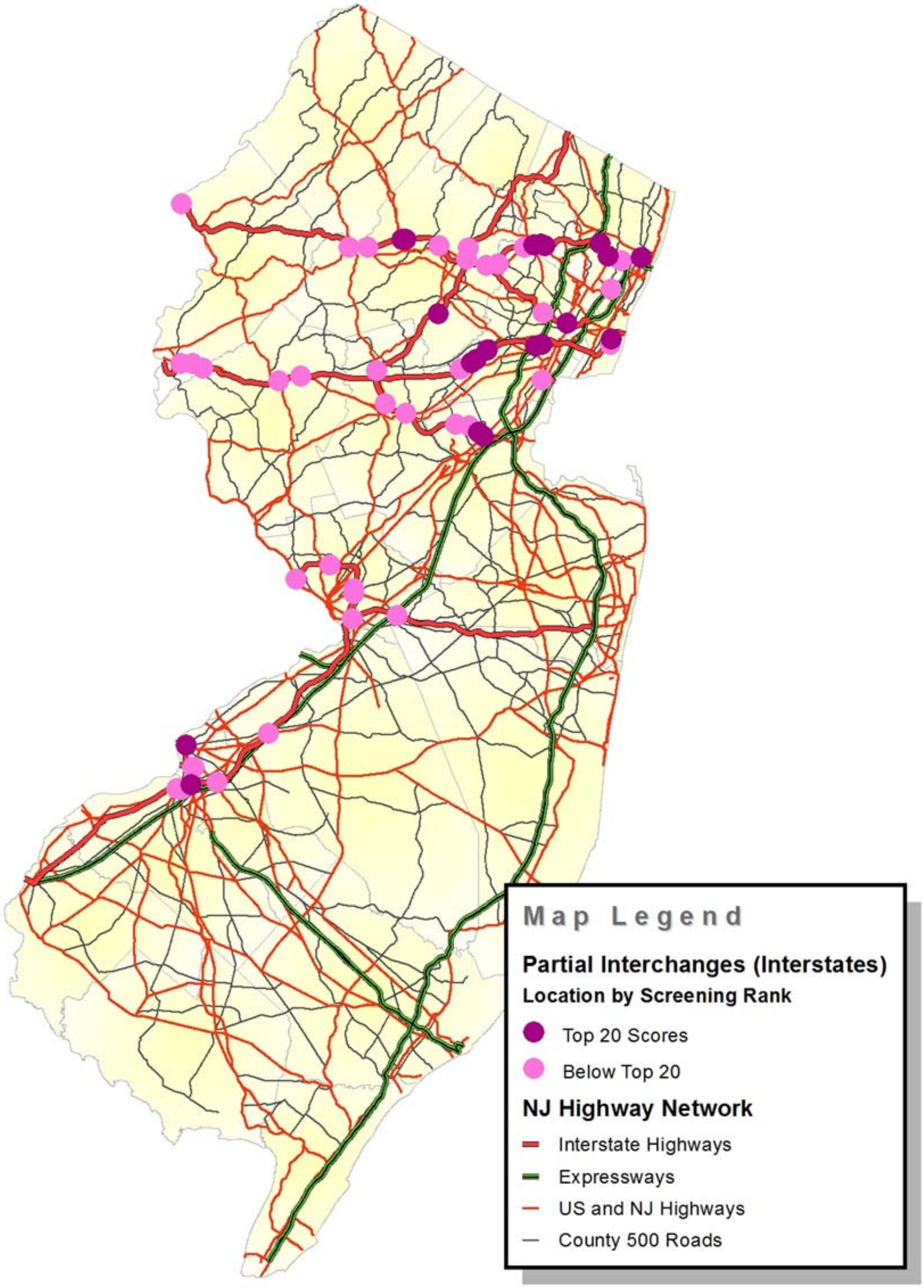

Figure 9. Location of Partial Interchanges with Top 20 Ranking

4.3.5 Screening Sensitivity Analysis

The purpose of conducting sensitivity analyses is to evaluate whether the top 20 interchanges would remain among the top 20 if some fundamental assumptions are changed. The sensitivity was tested by varying the criteria weights. Three additional weighting alternatives were introduced for this purpose, and these are summarized in Table 5 . The first alternative gives a 25 percent higher weight to the congestion criterion (an increase from 40 to 50 percent), and a corresponding 50 percent reduction in the weight of the truck activity criterion (a decrease from 20 to 10 percent). The second alternative increases the weight of land use (smart growth) criterion from 10 to 20percent (a 100 percent increase) and reduces the weight of the truck activity criterion from 20 to 10 percent (a 50 percent reduction). The third and final alternative reduced the weight of the congestion criterion from 40 to 30 percent (a 25 percent decrease) and increased the weight of the land use (smart growth) criterion from 10 to 20 percent (a 100 percent increase).

Table 5. Alternative Criteria Weights Used in the Sensitivity Analysis

Scoring Criteria	Alternative Criteria Weights			
	Adopted Weights	Alternative 1	Alternative 2	Alternative 3
Congestion	40%	50%	40%	30%
Truck Activity	20%	10%	10%	20%
Safety	20%	20%	20%	20%
Cross Road Functional Class	10%	10%	10%	10%
Land Use (Smart Growth)	10%	10%	20%	20%

The interchanges that ranked among the top 20 in all weighting alternatives are listed in Table 6. The table shows that 18 interchanges are consistently ranked among the top 20 in all weighting alternatives. They are shown in the upper portion of the table. Two interchanges ranked in top 20 with the adopted weights, but did not rank in the top 20 in at least one of the three sensitivity analysis alternatives:

- I-676 and Route 537, Interchange 5: did not rank in the top 20 in Alternative 1

- I-280 and NJ 21, Interchange 15: did not rank in the top 20 in Alternatives 1 and 2

On the other hand, the total scores of the following two interchanges did not rank in the top 20 with the adopted weights, but did make it into the top 20 after applying the alternative criteria weights:

- I-80 and US 46, Interchange 38: ranked in the top 20 in Alternatives 1 and 2
- I-78/N.J. Turnpike Extension and Hudson County 612, Interchange 14C: ranked in the top 20 in Alternative 1

The relatively consistent top-20 ranking of partial interchanges (with at most 10 percent variation) for varying criteria weights illustrated in the sensitivity analysis indicates that the final ranking is robust.

Table 6. Interchanges that Ranked in the Top 20 for the Adopted Weights and Three Weighting Alternatives

No.	Interchange	County
1	I-78/N.J. Turnpike Extension and Hudson County 622, Interchange 14C	Hudson
2	I-78 and Union County 655, Interchange 43	Union
3	I-78 and CR 527, Interchange 44	Union
4	I-78 and Route 527, Interchange 45	Union
5	I-78 and Garden State Parkway, Interchange 53	Union
6	I-78 and Winans Avenue, Interchange 54	Union
7	I-80 and Morris County 634, Interchange 34	Morris
8	I-80 and NJ 15, Interchange 34	Morris
9	I-80 and NJ 23, Interchange 53	Passaic
10	I-80 and Passaic County 642, Interchange 54	Passaic
11	I-80 and NJ 62, Interchange 55	Passaic
12	I-80 and NJ 17, Interchange 64	Bergen
13	I-80 and Bergen County 79 (east of Interchange 62)	Bergen
14	I-95/N.J. Turnpike and Broad Ave (Dana Place), Interchange 71	Bergen

No.	Interchange	County
15	I-287 and NJ 27, Interchange 2	Middlesex
16	I-287 and Route 501, Interchange 3	Middlesex
17	I-287 and Harter Road, Interchange 33	Morris
18	I-295 and NJ 42, Interchange 26	Camden

Note: The order in which the interchanges are listed does not reflect their ranking.

4.4 Modeling the Benefits of Interchange Improvements

The developed methodology for assessing the impact of improving partial interchange movements is similar to general benefit/cost analysis methods employed in evaluating the effect of transportation improvements. It compares the costs of constructing missing on- or off-ramps to the estimated benefits (or savings) in various user cost categories, including:

- Travel time: overall savings in travel time on the regional network (and corresponding cost) resulting from the improvement

- Fuel consumption: expected reduction due to improved ability of vehicles to operate in more efficient regimes on highways

Vehicle emissions: including pollutants NOx, HC, and CO, as well as reduction in carbon footprint

The main sources of data for this analysis are regional travel demand forecasting models that estimate the changes in VMT and VHT on each link of the regional network, resulting from the partial interchange improvements. The travel demand forecasting is a computer-based modeling approach used to predict the travel patterns of the population during a specific time period. It provides solutions in anticipation of potential future congestion problems in the transportation network. In this study, the regional travel demand models—NJRTM-E by NJTPA and the Travel Demand Model by DVRPC—are used to perform a “what-if” analysis to estimate the impact of the partial interchange upgrades on the transportation network. The NJRTM-E and DVRPC demand models are comprehensive and powerful enough to help with analyzing projects, developing a long-range plan, and determining compliance with air quality conformity standards.

The implementation of these two models is conducted with the following steps:

Step 1: Traffic assignment for the baseline scenario

Perform the traffic assignment with the existing interchange design and record VMT and VHT for each link in the model network.

Step 2: Identify the missing movements and modify the network by adding links that would facilitate these movements

The missing movements are added as new network links with capacities consistent with adjacent on- or off-ramps for the same interstate highway. For each analyzed interchange, all missing movements are added (assuming the improvement would entail a full interchange upgrade).

Step 3: Traffic Assignment for the upgrade (built) scenario

Perform the traffic assignment with the upgraded regional model network that includes the links facilitating missing movements. As in the baseline model, VMT and VHT data is collected for each link in the model network.

Step 4: Calculate the benefit of the upgrade as a difference between the system costs for the baseline and upgrade scenarios

The benefits are expressed as the cost savings stemming from reductions in road users' costs, including travel time cost (including both passenger cost and truck operating cost), vehicle emissions mitigation cost, and fuel cost. All of the savings are accrued across the model network on an annual basis and are calculated using VMT and VHT outputs from the model, and cost parameters specific to each cost category. Using the "before" (baseline, or "no-build") and "after" ("built") scenario results of travel demand models, the benefits of the interchange improvement project are estimated as reduction in various user costs between the two scenarios. The methodology associates sound economic theory with the outputs of travel demand forecasting models that assess the benefits of constructing missing movements at partial interchanges. The calculation of road users' costs for each cost category is described next.

4.4.1 Calculation of Travel Time Cost Savings

Travel time saving (ΔVHT) is calculated as a difference between the total travel time (i.e., VHT) in the baseline scenario and the total travel time in the upgrade scenario, both expressed in vehicle-hours. Note that total VHT is directly recorded from the travel demand model outputs.

$$\Delta VHT = VHT_{Base} - VHT_{Upgrade} \quad (4)$$

where:

ΔVHT = total VHT (i.e., travel time) change (vehicle-hours)

VHT_{Base} = total VHT in the baseline scenario (vehicle-hours)

$VHT_{Upgrade}$ = total VHT in the upgrade scenario (vehicle-hours)

To obtain the monetary value of the travel time savings, total travel time saving is calculated for passenger cars and trucks, and then multiplied by the appropriate value of travel time, respectively. Travel time cost per driver/passenger and cost of one hour of operating a truck are obtained from the Bureau of Labor Statics (BLS)[1] and the American Transportation Research Institute (ATRI) report[2], respectively.

4.4.2 Calculation of Fuel Consumption Savings

Vehicle fuel consumption savings are calculated as a function of vehicle flow parameters derived from the results of VMT, which are disaggregated by vehicle type, fuel type, and speed bins (in 5 mph increments from 0 to 105 mph). The vehicle and fuel types in New Jersey are classified using Mobile 6 data, and the percentage of each vehicle type and its fuel type is summarized in Table 7. The average price of gasoline and diesel in New Jersey, used to calculate the monetary value of fuel savings, was obtained from the U.S. Energy Information Administration (EIA) report[3].

With the classified vehicle type (i.e., auto and truck) and fuel type (i.e., gas and diesel) data, the average fuel consumption rate was obtained using IDAS (see Table 7). Therefore, the total fuel consumption amount for passenger car and truck can be computed as:

$$\begin{aligned} \Delta F_{Auto} &= (\Delta VMT_{SOV} + \Delta VMT_{HOV}) \times g_{auto}^{speed} \\ \Delta F_{Truck} &= \Delta VMT_{Truck} \times g_{Truck}^{speed} \end{aligned} \quad (5)$$

---

[1] Average New Jersey wage from BLS Occupational Employment and Wages (http://www.bls.gov/oes/current/oes_nj.htm)

[2] Katherine J. Fender and David A. Pierce. "An Analysis of the Operational Costs of Trucking: A 2011 Update," ATRI, June 2011

[3] http://www.eia.gov/petroleum/gasdiesel/

where,

ΔF_{auto} , ΔF_{Truck} = total fuel consumption change of passenger cars and trucks, respectively (gallons)

ΔVMT_{SOV}, ΔVMT_{HOV}, ΔVMT_{Truck} = total VMT change of SOVs, HOVs, and trucks, respectively (vehicle-miles)

g^{speed}_{Auto} , g^{speed}_{Truck} = average fuel consumption rate of passenger cars and trucks per speed bin (gallon/vehicle-miles)

The estimated fuel economy of passenger cars and trucks is given in **Table 8**.

Table 7. New Jersey Traffic Count Percentage based on Vehicle and Fuel Type

Mobile 6 Vehicle Type			Gasoline (%)	Diesel (%)
Light Duty Gasoline Vehicle	(LDGV)	Auto	52.73	
Light Duty Gasoline Truck 1	(LDGT1)	Auto	26.58	
Light Duty Gasoline Truck 2	(LDGT2)	Auto	8.75	
Heavy Duty Gasoline Vehicle	(HDGV)	Truck	2.79	
Light Duty Diesel Vehicle	(LDDV)	Auto		0.16
Light Duty Diesel Truck	(LDDT)	Auto		0.04
Heavy Duty Diesel Vehicle	(HDDV)	Truck		8.60
Motorcycle	(MC)	Auto	0.29	

Note: SOVs and HOVs are considered passenger cars (i.e., auto).

Table 8. Fuel Consumption Rate by Vehicle Type

SPEED BIN		Average Fuel Consumption (gal/vehicle-mile)		
>=	<	Auto (gas)	Truck(gas)	Truck(diesel)
0	5	0.540000	0.650000	0.450000
5	10	0.182000	0.310000	0.696000
10	15	0.123000	0.181000	0.489000
15	20	0.089000	0.135000	0.297000
20	25	0.068000	0.118000	0.185000
25	30	0.054000	0.120000	0.131000
30	35	0.044000	0.133000	0.110000
35	40	0.037000	0.156000	0.112000
40	45	0.034000	0.185000	0.122000
45	50	0.033000	0.223000	0.136000
50	55	0.033000	0.264000	0.153000
55	60	0.034000	0.310000	0.170000
60	65	0.037000	0.374000	0.187000
65	70	0.043000	0.439000	0.204000
70		0.052000	0.511000	0.221000

4.4.3 <u>Calculation of Vehicle Emissions Savings</u>

The emission rates and unit costs for HC, CO, and NOx (dependent on vehicle type and speed) were obtained from IDAS and used to calculate the monetary value of savings in vehicle emissions as a difference between the existing partial interchange and the upgraded interchange scenarios. The vehicle emissions savings are also calculated based on the results of VMT, which are disaggregated by vehicle type, fuel type, and speed bins (in 5 mph increments from 0 to 105 mph). The total vehicle emissions resulting from VMT can be calculated using equation 6 shown below.

$$\begin{bmatrix} \Delta E_{HC} = (\Delta VMT_{SOV} + \Delta VMT_{HOV} + \Delta VMT_{Truck}) \times e^{speed}_{HC\text{-}gas} + (\Delta VMT_{Truck} \times e^{speed}_{HC\text{-}diesel}) \\ \Delta E_{CO} = (\Delta VMT_{SOV} + \Delta VMT_{HOV} + \Delta VMT_{Truck}) \times e^{speed}_{CO\text{-}gas} + (\Delta VMT_{Truck} \times e^{speed}_{CO\text{-}diesel}) \\ \Delta E_{NOx} = (\Delta VMT_{SOV} + \Delta VMT_{HOV} + \Delta VMT_{Truck}) \times e^{speed}_{NOx\text{-}gas} + (\Delta VMT_{Truck} \times e^{speed}_{NOx\text{-}diesel}) \end{bmatrix} \quad (6)$$

where,

$\Delta E_{HC}, \Delta E_{CO}, \Delta E_{NOx}$ = total emission amount change of HC, CO, and NOx (tons)

$e^{speed}_{HC\text{-}gas}, e^{speed}_{CO\text{-}gas}, e^{speed}_{NOx\text{-}gas}$ = gas vehicle emission rate of HC, CO, and NOx per speed bin (grams/mile)

$e^{speed}_{HC\text{-}diesel}, e^{speed}_{CO\text{-}diesel}, e^{speed}_{NOx\text{-}diesel}$ = diesel vehicle emission rate of HC, CO, and NOx per speed bin (grams/mile)

To utilize the vehicle emission rate data from IDAS, the traffic count percentage shown in Table 6 was re-categorized based on vehicle type (e.g., auto and truck) and fuel type (e.g., gas and diesel). To this end, it was assumed that LDGV, LDGT1, LDGT2, LDDV, LDDT, and MC are autos, while HDGV and HDDV are trucks. The new traffic percentage is summarized in **Table 9**.

Table 9. Traffic Percentage based on Fuel and Vehicle Types

Fuel Type	Vehicle Type	
	Auto	Trucks
Gasoline	100%	25%
Diesel	0%	75%

The emission rates per speed and vehicle type for HC, CO, and NOx are shown in Tables 10, 11, and 12, respectively.

Table 10. Hydrocarbon (HC) Emission Rates (grams per mile)

Vehicle Speed (mph)		Vehicle Class								
>=	<	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	7.0773	8.2920	9.9337	8.7847	10.3120	1.0950	1.5683	4.3963	11.6057
5	10	2.8982	3.4318	4.1086	3.6348	5.4950	0.9044	1.2952	3.6316	7.9760
10	15	1.8914	2.2176	2.6422	2.3452	3.7186	0.7160	1.0250	2.8750	6.2432
15	20	1.5142	1.7682	2.1008	1.8678	2.7752	0.5794	0.8298	2.3268	5.5900
20	25	1.2562	1.4786	1.7516	1.5606	2.1964	0.4794	0.6864	1.9248	5.2556
25	30	1.0604	1.2676	1.4948	1.3358	1.8324	0.4056	0.5806	1.6280	5.0318
30	35	0.9246	1.1220	1.3180	1.1808	1.5910	0.3506	0.5020	1.4076	4.8596
35	40	0.8240	1.0150	1.1884	1.0672	1.4270	0.3098	0.4436	1.2444	4.7296
40	45	0.7462	0.9330	1.0890	0.9798	1.3146	0.2800	0.4010	1.1242	4.6444
45	50	0.6852	0.8692	1.0122	0.9122	1.2378	0.2586	0.3704	1.0384	4.6002
50	55	0.6608	0.8432	0.9812	0.8846	1.1852	0.2442	0.3498	0.9808	4.5930
55	60	0.6808	0.8632	1.0064	0.9060	1.1556	0.2360	0.3376	0.9468	4.7352
60	65	0.7492	0.9348	1.0946	0.9828	1.1470	0.2326	0.3332	0.9340	5.0916
65	70	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
70	75	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
75	80	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
80	85	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050
85	90	0.7920	0.9780	1.1490	1.0290	1.1520	0.2330	0.3340	0.9360	5.3050

Table 11. Carbon Monoxide (CO) Emission Rates (grams per mile)

Vehicle Speed (mph)		Vehicle Class								
>=	<	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	54.3420	58.7417	69.8430	62.0720	52.8050	4.3620	4.9317	32.9103	#######
5	10	28.9404	31.9686	38.0100	33.7810	38.1226	3.2442	3.6682	24.4774	68.1184
10	15	19.7536	22.2862	26.4978	23.5498	25.8838	2.2750	2.5726	17.1658	36.9148
15	20	16.1586	18.4970	21.9926	19.5460	18.5720	1.6702	1.8884	12.6006	25.5384
20	25	13.0598	15.2100	18.0844	16.0724	14.0826	1.2832	1.4508	9.6818	19.7182
25	30	10.0958	12.0222	14.2942	12.7038	11.2850	1.0320	1.1670	7.7866	15.8836
30	35	8.0646	9.8380	11.6966	10.3952	9.5568	0.8686	0.9824	6.5548	13.0582
35	40	6.5854	8.2466	9.8050	8.7140	8.5528	0.7656	0.8656	5.7760	11.0046
40	45	5.4596	7.0358	8.3654	7.4346	8.0890	0.7062	0.7982	5.3274	9.6282
45	50	4.6038	6.1154	7.2710	6.4620	8.0852	0.6816	0.7706	5.1432	8.7950
50	55	4.4130	5.9100	7.0270	6.2450	8.5400	0.6890	0.7788	5.1974	8.6310
55	60	5.2210	6.8646	8.1620	7.2538	9.5328	0.7284	0.8240	5.4976	12.7880
60	65	7.2410	9.2516	10.9998	9.7760	11.2456	0.8070	0.9122	6.0872	23.1808
65	70	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
70	75	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
75	80	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
80	85	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170
85	90	8.4530	10.6840	12.7030	11.2890	12.6970	0.8740	0.9880	6.5960	29.4170

Table 12. Nitrogen Oxide (NOx) Emission Rates (grams per mile)

Vehicle Speed (mph)		Vehicle Class								
>=	<	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	1.7417	2.0820	2.5550	2.2243	3.1013	1.8387	2.1187	11.0553	0.8187
5	10	1.4190	1.6962	2.0814	1.8116	3.2240	1.5764	1.8164	9.4764	0.7198
10	15	1.3020	1.5566	1.9100	1.6626	3.3840	1.3258	1.5278	7.9706	0.6864
15	20	1.2564	1.5020	1.8432	1.6044	3.5446	1.1556	1.3314	6.9472	0.7246
20	25	1.2618	1.4812	1.8174	1.5820	3.7050	1.0434	1.2024	6.2744	0.7970
25	30	1.2904	1.4870	1.8248	1.5884	3.8650	0.9766	1.1254	5.8722	0.8746
30	35	1.3098	1.4914	1.8300	1.5928	4.0250	0.9472	1.0914	5.6950	0.9414
35	40	1.3242	1.4942	1.8336	1.5962	4.1850	0.9522	1.0968	5.7234	0.9896
40	45	1.3350	1.4966	1.8362	1.5986	4.3452	0.9914	1.1424	5.9604	1.0226
45	50	1.3512	1.5094	1.8522	1.6122	4.5060	1.0700	1.2330	6.4322	1.0588
50	55	1.4992	1.7210	2.1118	1.8384	4.6660	1.1964	1.3786	7.1930	1.1982
55	60	1.6918	1.9988	2.4526	2.1350	4.8260	1.3862	1.5974	8.3346	1.3710
60	65	1.8842	2.2768	2.7936	2.4316	4.9860	1.6648	1.9182	10.0082	1.5438
65	70	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
70	75	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
75	80	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
80	85	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470
85	90	2.0000	2.4430	2.9980	2.6100	5.0820	1.8830	2.1700	11.3240	1.6470

4.4.4 Calculation of the Total Road User Cost Savings (i.e., Benefits)

To calculate a benefit/cost ratio of improving partial interchanges on the existing New Jersey roadway network, it is necessary to express all of the benefits in monetary values. To obtain the total savings in dollar amounts, the savings in travel time, vehicle emissions, and fuel must be multiplied by the appropriate unit costs. Thus, the total user cost savings can be calculated as follows:

Travel Time

$$\Delta C_{VHT} = (\Delta VHT_{SOV} \times C_{pass}) + (\Delta VHT_{HOV} \times C_{pass} \times VOR) + (\Delta VHT_{Truck} \times C_{Truck}) \quad (7)$$

where,

ΔC_{VHT} = total travel time cost savings due to interchange upgrade (in $)

ΔVHT_{SOV}, ΔVHT_{HOV}, ΔVHT_{TRUCK} = total VHT change for SOV, HOV, and truck, respectively (vehicle-miles)

C_{pass}, C_{TRUCK} = average value of time for passenger car and truck ($/person-hour)

VOR = vehicle occupancy rate (persons/vehicle)

Fuel Consumption

$$\Delta C_{Fuel} = [(\Delta VMT_{SOV} + \Delta VHT_{HOV}) \times C_{gas}] + (\Delta VMT_{TRUCK} \times C_{diesel}) \qquad (8)$$

where,

ΔC_{Fuel} = total fuel consumption savings due to interchange upgrade ($)

C_{gas}, C_{diesel} = market price at the pump of gasoline and diesel ($/gallon)

Vehicle Emission

$$\Delta C_{emission} = (\Delta E_{HC} \times C_{HC}) + (\Delta E_{CO} \times C_{CO}) + (\Delta E_{NOx} \times C_{NOx}) \qquad (9)$$

where,

$\Delta C_{emission}$ = total vehicle emission cost savings due to interchange upgrade ($)

C_{HC}, C_{CO}, C_{NOx} = unit cost savings from the reduction of emissions of HC, CO, and NOx respectively ($/ton)

Table 13. Dollar Value of Parameters Used in Calculations

Parameter	Value	Measure	Source
Travel Time Cost per driver or passenger	12.20	$/hour	Average NJ wage from BLS Occupational Employment and Wages (50% of the average NJ hourly wage)
Truck operating cost	45.90	$/hour	Bureau of Labor Statistics[4] and ATRI[5]
HC emissions per hour of delay	0.000025676	tons	Guin *et al.*, 2007
CO emissions per hour of delay	0.00033869	tons	Guin *et al.*, 2007

[4] Hourly mean wage of truck drivers for NJ. From United States Department of Labor, Bureau of Labor Statistics, "Occupational Employment and Wages, May 2010," (http://www.bls.gov/oes/current/oes533032.htm) accessed June 28, 2011, website date May 17, 2011.

[5] Katherine J. Fender and David A. Pierce, "An Analysis of the Operational Costs of Trucking: A 2011 Update", ATRI June 2011, Table ES2.

Parameter	Value	Measure	Source
NOx emissions per hour of delay	0.000036064	tons	Guin *et al.*, 2007
Cost savings because of HC reduction	6,700	$/ton	Guin *et al.*, 2007
Cost savings because of CO reduction	6,360	$/ton	Guin *et al.*, 2007
Cost savings because of NOx reduction	12,875	$/ton	Guin *et al.*, 2007
Average price of gasoline in NJ	2.654	$/gallon	U.S. Department of Energy, Energy Information Administration (EIA)
Average price of diesel in NJ	2.918	$/gallon	

4.5 Estimation of Construction Costs

4.5.1 <u>Methodology and Discussion</u>

The methodology used in this research is based on a pragmatic approach to review and incorporate all available data pertaining to constructing missing moves of interchanges in New Jersey. The development of a cost estimating methodology began by reviewing bids for previous interchange improvement construction projects. An inventory search was performed to identify the interchange improvement construction projects. The inventory of possible matches was retrieved from five main data sources:

1. Statewide Transportation Improvement Program (STIP – compilation of the three MPO TIPs)
2. NJTPA Transportation Improvement Program (TIP)
3. South Jersey Transportation Planning Organization (SJTPO) TIP
4. DVRPC TIP
5. NJDOT Construction Services database of Awarded Projects for FY 2005–2012 (2011 and 2012 did not have any reasonably comparable projects)

Data review began with projects within the selected data range using the word “ramp” or “interchange” in the title. Those projects were reviewed, where possible, to determine if the project was, indeed, an interchange improvement project , rather than one that used the word “ramp” or “interchange” to describe boundary limits or project termini. Those projects that qualified the review criteria were documented, and all possible information was collected.

The team reviewed the records for unit costs, cost breakdowns by element of construction, or other breakdowns in order to develop trends to use in rudimentary cost estimates. Using the NJDOT Construction Services database listings of bid tabulations, three construction projects were identified and used to determine if the bid tabulations could be used to develop idealized cost trends:

1. Route 46 Interchange Improvements, Contract No. 056960384
2. Route 280 at Garden State Parkway Interchange 145, Contract No. 011053110
3. Route I-78 & Garden State Parkway Interchange 142, Contract No. 052985450

As shown in Table 14, the state provides bid tabulations for each contract, which provides some insight concerning construction pricing. However, due to the infrequency of interchange improvement projects, pricing did not appear to align.

The three projects ranged in pricing from $17 million (Route 280 at GSP) to $121 million (Route I-78 & GSP). Only one of the projects included missing moves, where the other two projects improved the interchanges’ operations. In addition, bidders varied widely in road and bridge items for each construction project. Table 15 shows the differences between apparent low bidders and second low bidders for the three projects.

Table 14. State Interchange Improvement Projects (2005–2011)

STATE PROJECTS				
Award Date	**Contractor**	**Project Description**	**Amount**	**Missing Moves**
6/21/2005	Anselmi & DeCicco Inc. Maplewood NJ	Route 46 Contract No. 056960384, Interchange Improvements, Route 46 from the Vicinity of Fairfield Road to East of Galesi Drive, Route 23 from the Vicinity of North Leg to South of West Belt Highway, Township of Wayne, Passaic County, Federal Project NHS-IBT-7802(148), PE1606507, CE1606536 DP04133.	$65,678,424.80	0
6/15/2006	A. Servidone, Inc., B. Anthony Constr. Co., Inc. JV Old Bridge, NJ	Route 280 at Garden State Parkway Interchange 145, Contract No. 011053110; Grading, Paving, Drainage & Structures, from Burnet Street to Steuben Street, City of East Orange, County of Essex; Federal Project No: IM-280-6(094), PE No: 0730514, CE No: 0730515 DP No:06106	$17,043,275.20	0
4/24/2008	Union Paving & Construction Co. Inc. Mountainside NJ	Route I-78 & Garden State Parkway Interchange 142,Contract No. 052985450: InterchangeImprovements, Townships of Union and Hillside in Union County, Township of Irvington in Essex County, Essex and Union Counties; Federal Project No. HPP-NH-078-5(094), PE2203939, CE2204556 DP# 07169	$121,960,705.95	2

Table 15. Five Lowest Bids for State Interchange Projects

Project Name	Contract No.	Missing Moves	Low Bidder	Second Low Bidder	Third Low Bidder	Fourth Low Bidder	Fifth Low Bidder
Route 46 Interchange Improvement	056960384	Improvements	$ 65,678,424.80	$ 74,436,443.02	$ -	$ -	$ -
Route 280 at Garden State Parkway Interchange 145	011053110	Improvements	$ 17,043,275.20	$ 17,979,274.35	$ 18,724,705.10	$ 18,789,680.00	$ 20,510,401.15
Route I-78 & Garden State Parkway Interchange 142	052985450	2 New moves	$ 121,960,705.95	$ 136,382,424.21	$ 139,399,999.68	$ 143,690,404.13	$ 162,474,261.00

The bids identified two problems for the team. First, the team would not be able to lump costs for interchange improvements without construction plans. Second, the high variability between bidders, such as the $40 million difference between apparent low bidder and fifth bidder for the Route I-78 & Garden State Parkway Interchange 142 project, meant that consistency within the data would be difficult to attain. With only three projects driving the data, two of which incorporated improvements to interchanges rather than completing missing moves, the team opted to abandon this approach and identify other studies that could provide a consistent basis for cost estimates.

The team identified two resources that were ultimately used for developing cost estimates: Arkansas Highway Road Design Division[6] and a construction cost comparison survey completed by the Washington Department of Transportation (WSDOT) in 2002[7]. Combined, the two resources provide more consistency in construction cost estimate results. In order to develop cost estimates for the construction of missing moves for each partial interchange, the team developed unit costs for a variety of possible improvements. The unit costs were based on a worksheet developed by the Arkansas cost per mile estimating tool, and modified the WSDOT survey using a correction factor for New Jersey.

The spreadsheet is organized to provide the user with two options to determine crude order-of-magnitude cost estimates:

- Option A – a granular cost estimate that requires the user to identify “feasible” improvements
- Option B – a “one-size-fits-all” cost estimate that does not require identifying “feasible” improvements

In order to demonstrate the tool, the team developed construction cost estimates for the top 10 partial interchanges identified through a previous task in this research project. As part of this work, the team investigated the 10 sites for feasible construction improvements to complete the missing moves of each partial interchange.

The words “feasible,” “feasibility,” etc., are not specifically defined in Title 23 U.S.C. or in 23 CFR. Within the context of this research, the meaning of “feasibility” conforms to the following guidelines provided by the Federal Highway Administration (FHWA):

- The degree to which given alternative modes, management strategy, design, or location is economically justified
- The degree to which such an alternative is considered preferable from an environmental or social perspective

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[6] Arkansas Highway Road Design Division, Cost per Mile, July 2011

http://www.arkansashighways.com/roadway_design_division/Cost%20per%20Mile%20JULY%202011.pdf

[7] Washington State Department of Transportation Construction Cost Comparison Survey, 2002

http://www.wsdot.wa.gov/biz/construction/pdf/I-C_Const_Cost.pdf

- The degree to which eventual construction and operation of such an alternative can be financed and managed

This is critical to understanding the methodology, as the research team purposely omitted Option A cost estimates at various interchanges on the basis that the team could not identify a feasible construction option within a reasonable study period. Instead, the team identified the Option B construction cost estimate as a means of establishing a baseline construction cost for comparison of other interchanges.

As stated previously, Option A is more granular in that the team investigated each site using web-based tools such as Google maps, Google Earth, and Bing maps to ascertain the lay of the land and determine feasible option or options for the missing move or moves. The following items were considered as part of construction for each project:

1. Roadways (new ramp, widening)

2. Bridges (new, widening, or replacement)

3. Traffic signalization (new or improvement)

4. Utility accommodations (temporary and/or permanent)

5. Stormwater (detention basins, structural improvements)

6. Miscellaneous structures (sign structures, retaining walls)

The six items were matched closely with the categories and items described in the cost-estimate worksheet:

1. New roads

2. Bridges and box culverts

3. Widening existing roadway

4. Reconstruction

5. Overlays

6. Signals

7. Signals with improvements

The spreadsheet does not include all conceivable costs incurred in construction. In particular, the spreadsheet did not include the following in the construction estimates:

1. Right of way costs

2. Utility accommodation costs

As a comparison of the granular Option A construction cost estimate, the team developed a second option construction cost estimate. Option B is simply a one-size-fits-all estimate for completing the interchange. The cost figure is based on the Arkansas Highway Road Design Department's estimate to complete an interchange. According to a discussion with a representative of the Arkansas Highway Road Design Department, the estimate provided in their document refers to a complete "simple" interchange with no additional appurtenances (such as additional bridges, retaining walls, signals, etc). Thus, the one-size-fits-all estimate should be treated as a single lump sum, which is not all-inclusive of anticipated costs but rather a figure to be used for comparison purposes only. In some cases, the Option B cost estimate could fall well below the actual construction costs. For example, construction costs for the I-78 & Garden State Parkway interchange reached $120 million, approximately five times that of the Option B estimate.

The two options will vary, and Option A will most likely be a lower-bound estimate. However, it will be difficult to reach an upper-bound estimate based on the myriad of unknowns. For the purposes of initial discussion, and as a means of achieving progress, the team considered construction cost estimates quasi-reasonable values for completing "typical" New Jersey interchanges.

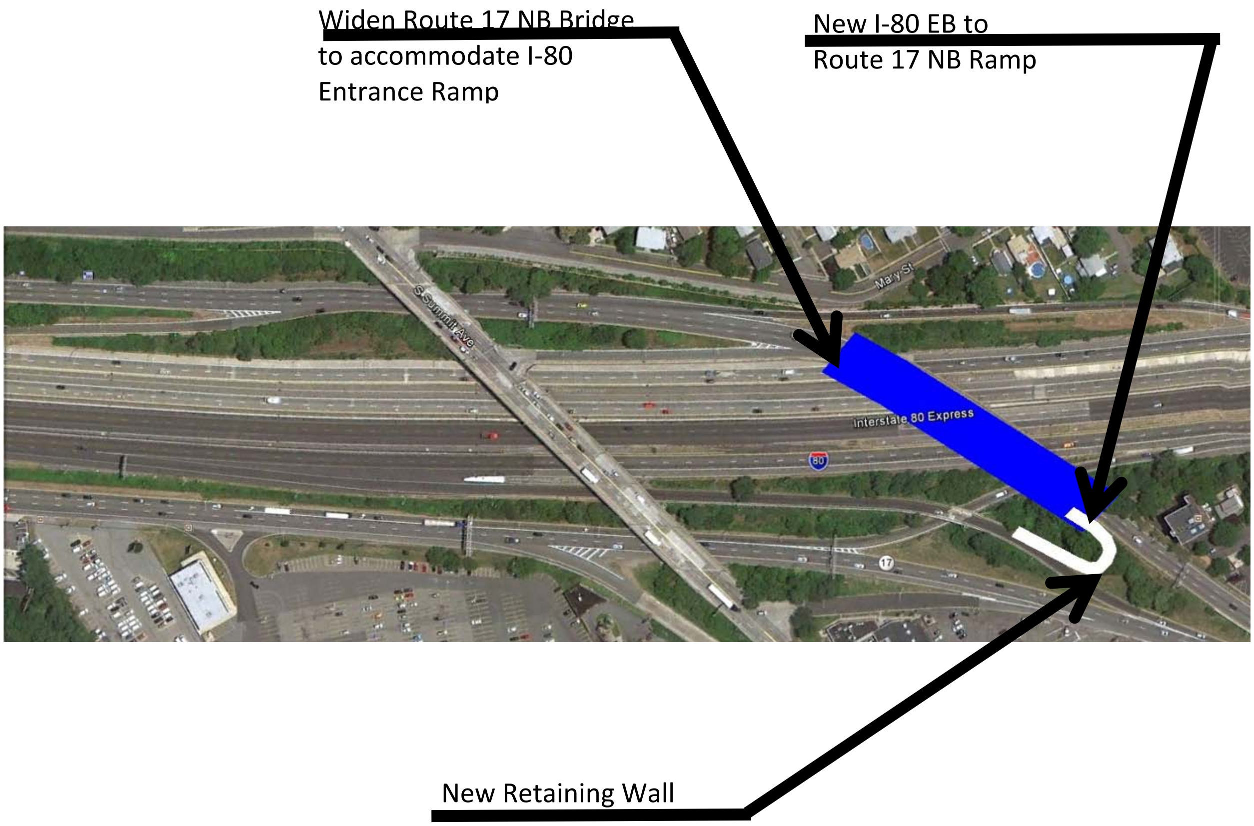
4.5.2 Interchange Review

The following sections provide detail of each interchange investigated, including discussion on the feasible options. Table 16 provides a list of studied interchanges, along with screening score and notes indicating feasible construction improvements:

Table 16. Partial Interchange Ranking

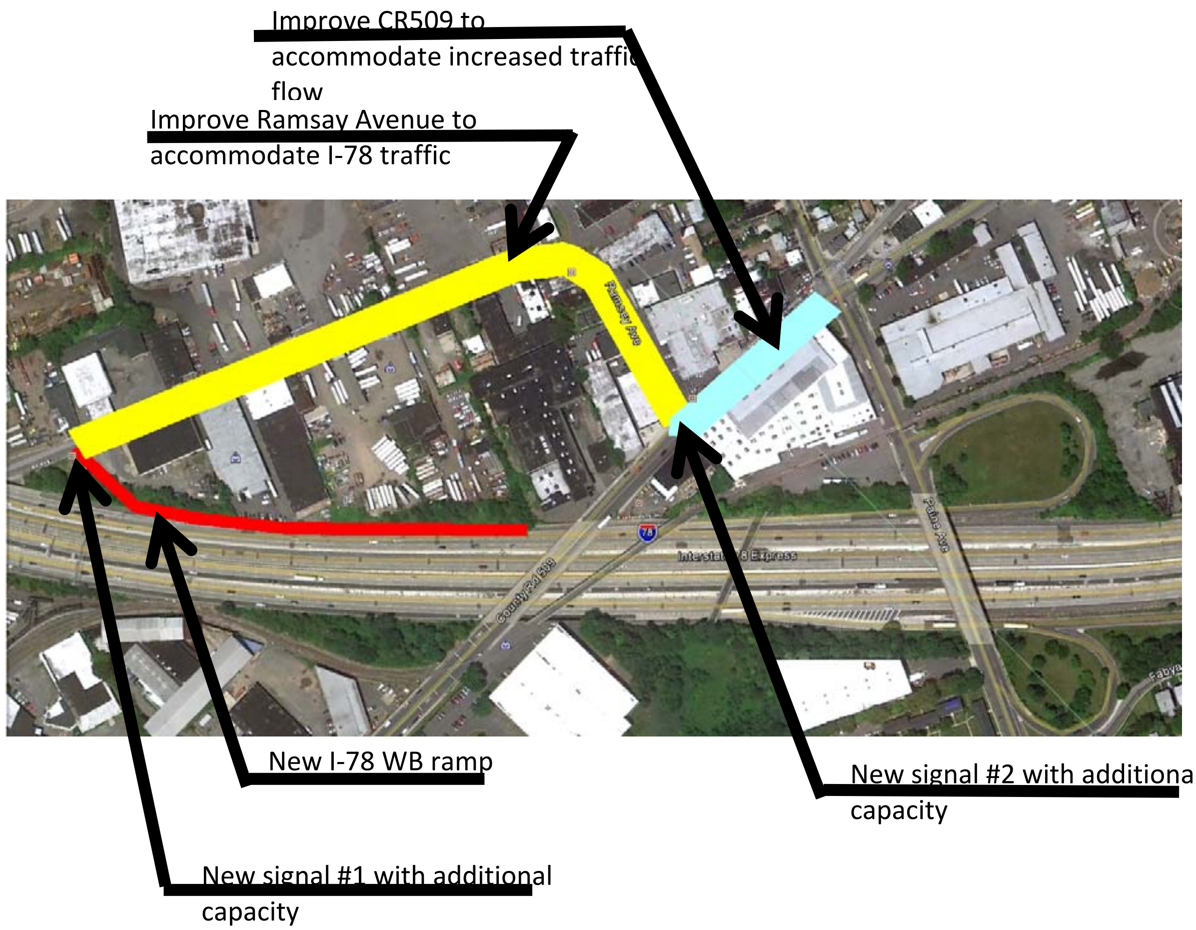
No.	Description	County	Screening Score	Notes
1	I-80 and NJ17	Bergen	86	Add new I-80 EB ramp and widen State Route 17 NB bridge
2	I-78 and Winans Ave, Interchange 54	Union	86	New I-78 WB ramp to Ramsey Avenue. Roadway improvements to Ramsey Avenue and CR509, leading to signal improvements at Winans Avenue and CR509.
3	I-80 and NJ 23, Interchange 53	Passaic	82	New I-80 entrance/exit ramps at Two Bridges Rd to provide access to Route 23 via 2 Bridges Road south to State Route 46 EB.
4	I-80 and NJ 62, Interchange 55	Passaic	78	Improve existing roadway network to accommodate increased traffic through Furler Street, Minninsk Road, and Vreeland Avenue. Improve the signalized intersection at State Route 62 and Furler Street
5	I-287 and NJ 27, Interchange 2	Middlesex	78	Realign I-287 NB exit ramp, construct new I-287-NB entrance ramp at new signalized intersection of State Route 27 and Bridge Street. Construct new I-287 SB exit ramp and widen I-287 over Amtrak Northeast Corridor. Improve signalized intersection at Vineyard Road to accommodate additional capacity.
6	I-78 and CR 527, Interchange 44 & 45	Union	74	No feasible options were identified. As an alternate, improve the Diamond Hill Road Interchange (Int #43) to provide access to CR 527
7	I-95, NJ Turnpike and Broad Ave, Interchange 71	Bergen	74	No feasible options were identified. As an alternate, improve roads at interchange 69
8	I-676 and County Route 537, Interchange 5	Camden	70	No feasible options were identified
9	I-78 and Diamond Hill Road, Interchange 43	Union	72	Realign I-78 WB exit ramp, construct new I-78 WB entrance ramp at new signalized intersection of CR 655. Widen CR 655 to accommodate additional traffic.
10	I-295 and NJ 33, Interchange 63	Mercer	58	No feasible options were identified

1. I-80 and State Route 17 – Interchange 64



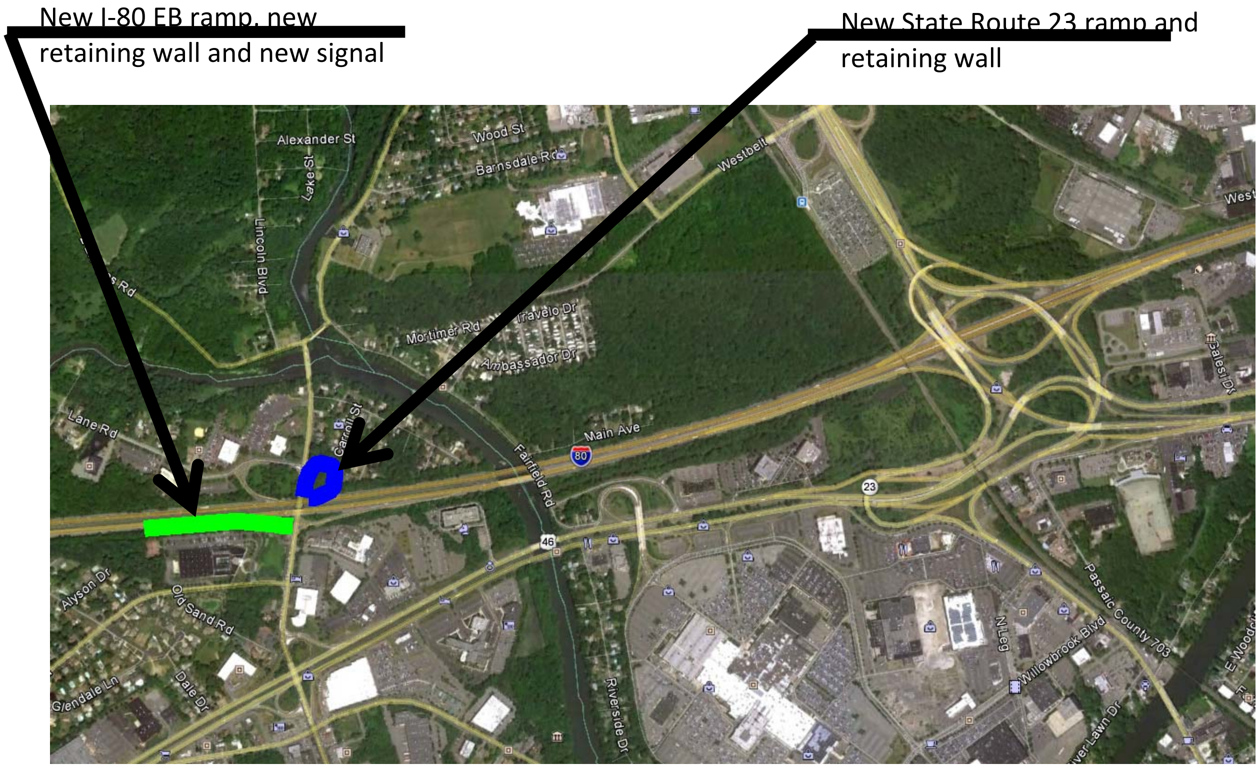
Interchanges 64 and 64A on Interchange I-80 function together as a partial interchange, providing connection between I-80 and State Route 17 in Bergen County. Interchange 64 requires one additional move to provide access from I-80 eastbound to Route 17 northbound. In order to provide access, the team determined it may be feasible to improve the existing I-80 eastbound ramp that provides access to Route 17 southbound, by adding a hairpin turn within the vegetated median, and connecting to Route 17 northbound. Due to potential grading issues, it is anticipated that the ramp would need to be supported by a new retaining wall. In addition, the new ramp may result in the need for widening the Route 17 northbound bridge over I-80.

2. I-78 and Winans Avenue – Interchange 54



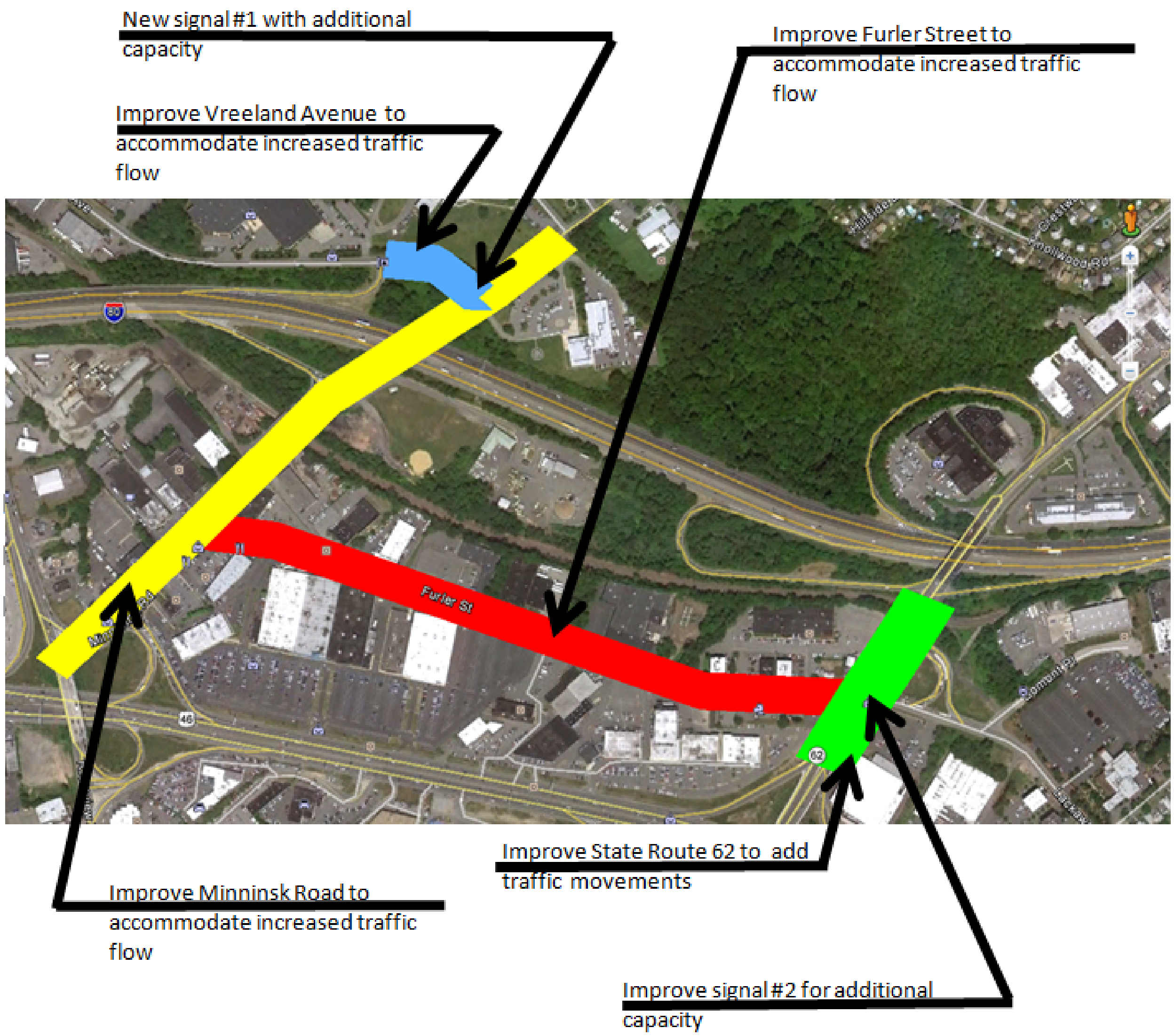
Interchange 54 provides access to Interstate I-78 at Winans Avenue in Union County. The interchange has two missing moves, I-78 westbound to Winans Avenue eastbound and westbound. The team determined it may be feasible to construct a new ramp from I-78 westbound to Ramsey Avenue. The roadway leading to Winans Avenue would need improvements from Ramsey Avenue to Chestnut Avenue (CR509), as well as signal improvements at Winans Avenue and Chestnut Avenue. These improvements would provide I-80 westbound traffic access to Winans Avenue eastbound and westbound.

3. I-80 and State Route 23 – Interchange 53



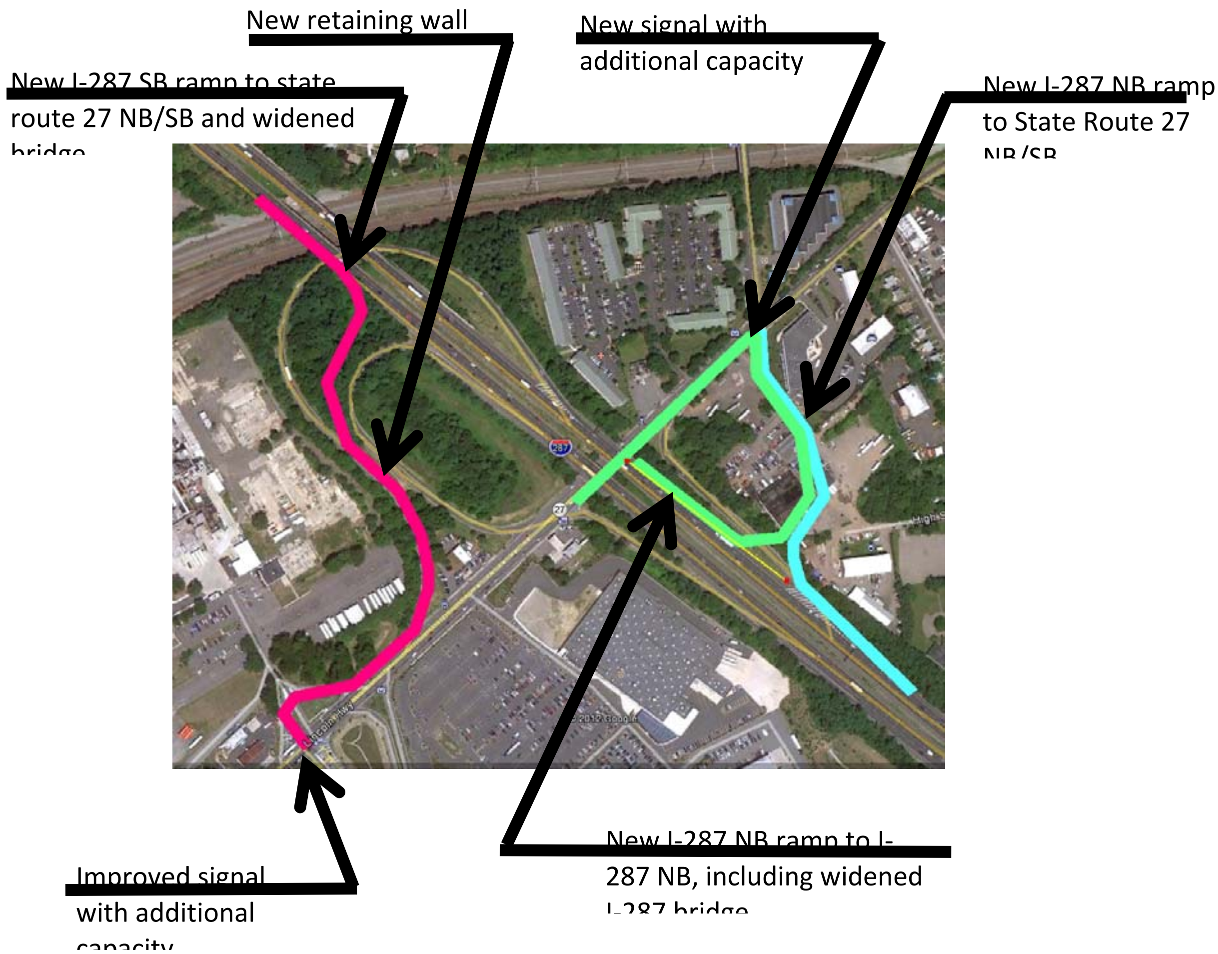
Interchange 53 provides I-80 traffic access to State Route 23 in Passaic County. The interchange is missing an I-80 eastbound exit to Route 23 northbound and southbound; and Route 23 southbound to I-80 westbound. The team did not find a feasible option to include the missing moves within the existing interchange. Instead, the team opted to improve interchange 52 by adding new I-80 entrance and exit ramps at Two Bridges Rd, which would provide access to Route 23 via Two Bridges Road south and State Route 46 eastbound. The improvements would likely include retaining walls to mitigate grading issues and a new signalized intersection at the end of the I-80 eastbound ramp at Two Bridges Road.

4. *I-80 and State Route 62 – Interchange 55*



Interchange 55 provides Interchange I-80 traffic access to State Route 62 in Passaic County. The interchange is missing the following moves: I-80 eastbound to Route 62 northbound and southbound; Route 62 northbound and southbound to I-80 westbound. The team did not find a feasible option to include the missing moves within the existing interchange. Instead, the team developed an option to improve existing infrastructure in order to provide similar access via interchange 54. The improvements include additional capacity to Route 62 by way of a left turn lane onto Furler Street, improving the existing signal at Route 62 and Furler Street; widening Furler street to accommodate the additional traffic flow; improving Minninsk Road to accommodate the additional traffic flow; improving Vreeland Avenue between I-80 and Minninsk Road to accommodate the additional traffic flow; and installing a new signal at Minninsk Road and Vreeland Avenue to control left turns onto Vreeland Avenue.

5. I-287 and State Route 27 – Interchange 2



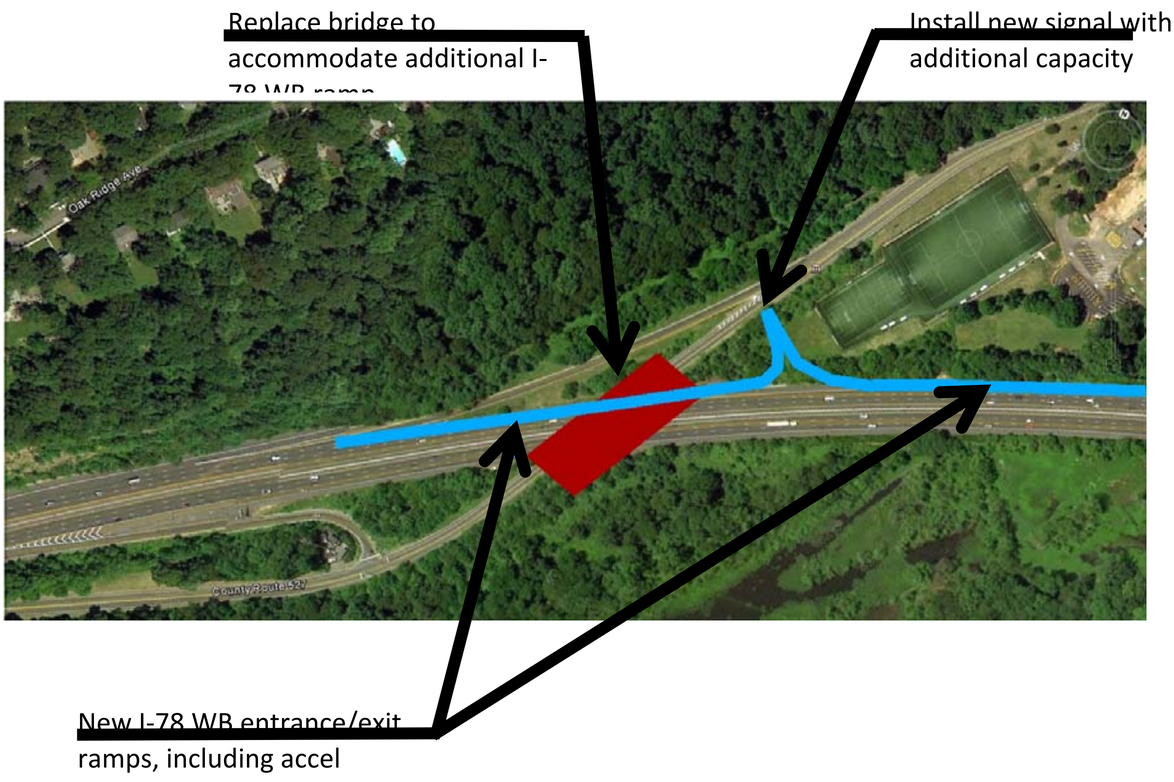
Interchange 2 provides I-287 traffic access to State Route 27 in Middlesex County. This interchange does not provide I-287 southbound traffic access to Route 27 in either direction, and does not provide Route 27 traffic access to I-287 northbound. In order to complete the interchange, the team considered the following improvements:

1. Realigning the I-287 northbound exit ramp
2. Constructing a new I-287 northbound entrance ramp
3. Installing a new signalized intersection at State Route 27 and Bridge Street

4. Constructing a new I-287 southbound exit ramp and widening I-287 over Amtrak Northeast Corridor

5. Improving the signalized intersection at Vineyard Road to accommodate additional capacity from I-287 southbound traffic heading to Route 27 northbound

6. I-78 and CR 527 – Interchanges 44 & 45



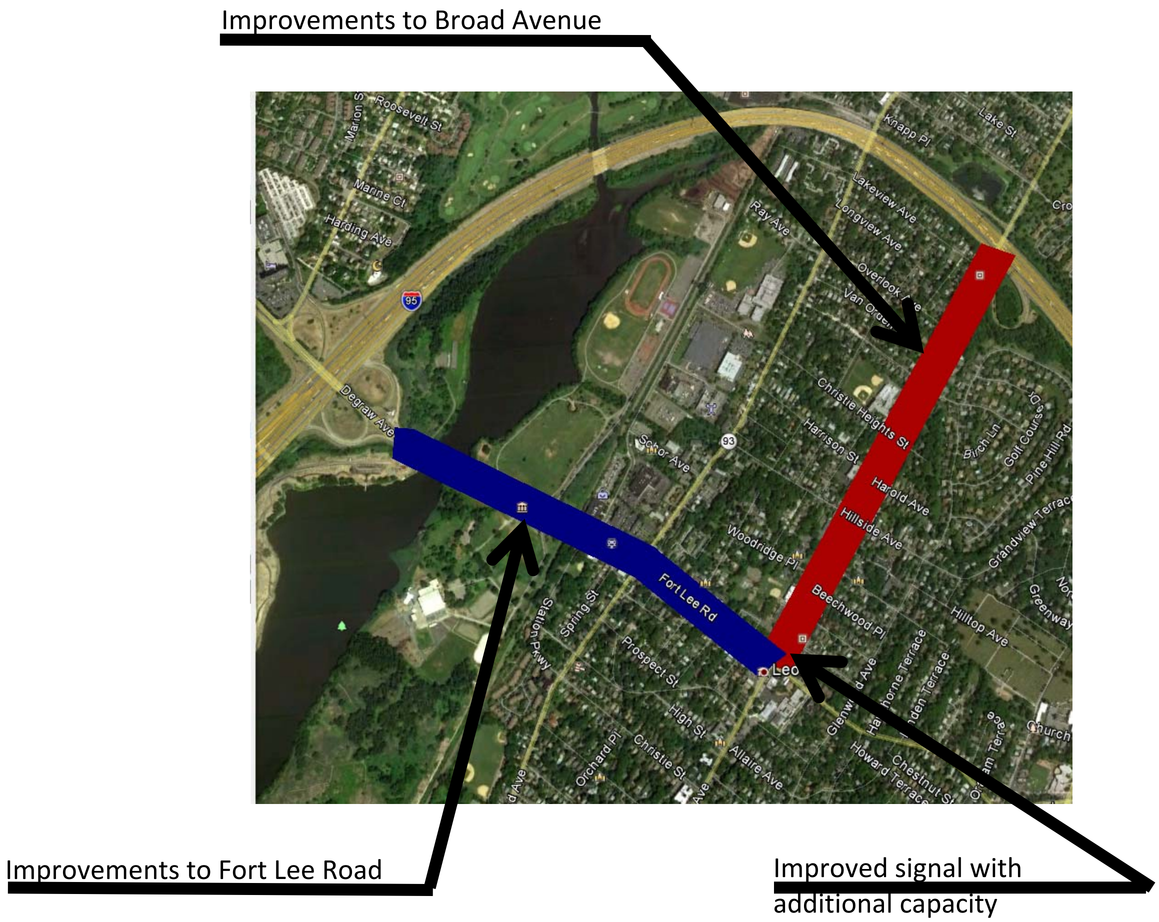
Interchange 44 provides I-78 eastbound traffic access to CR 527 only. I-78 westbound traffic does not have access to CR 527, in large part due to the excessive grade differential on the north side of I-78. The team found this to be significant enough to consider improvements to Interchange 44 unfeasible. Instead, the team reviewed improvements to Interchange 45 as an option to complete the missing moves. For this study, the team considered the following improvements feasible for Interchange 45:

1. Construct new I-78 entrance and exit ramps at Interchange 45

2. Reconstruct the CR 527 bridge over I-78 to provide sufficient lateral clearance for the new I-78 entrance ramp

3. Install a new signal to control traffic at the new ramps

7. I-95 and Broad Avenue – Interchange 71

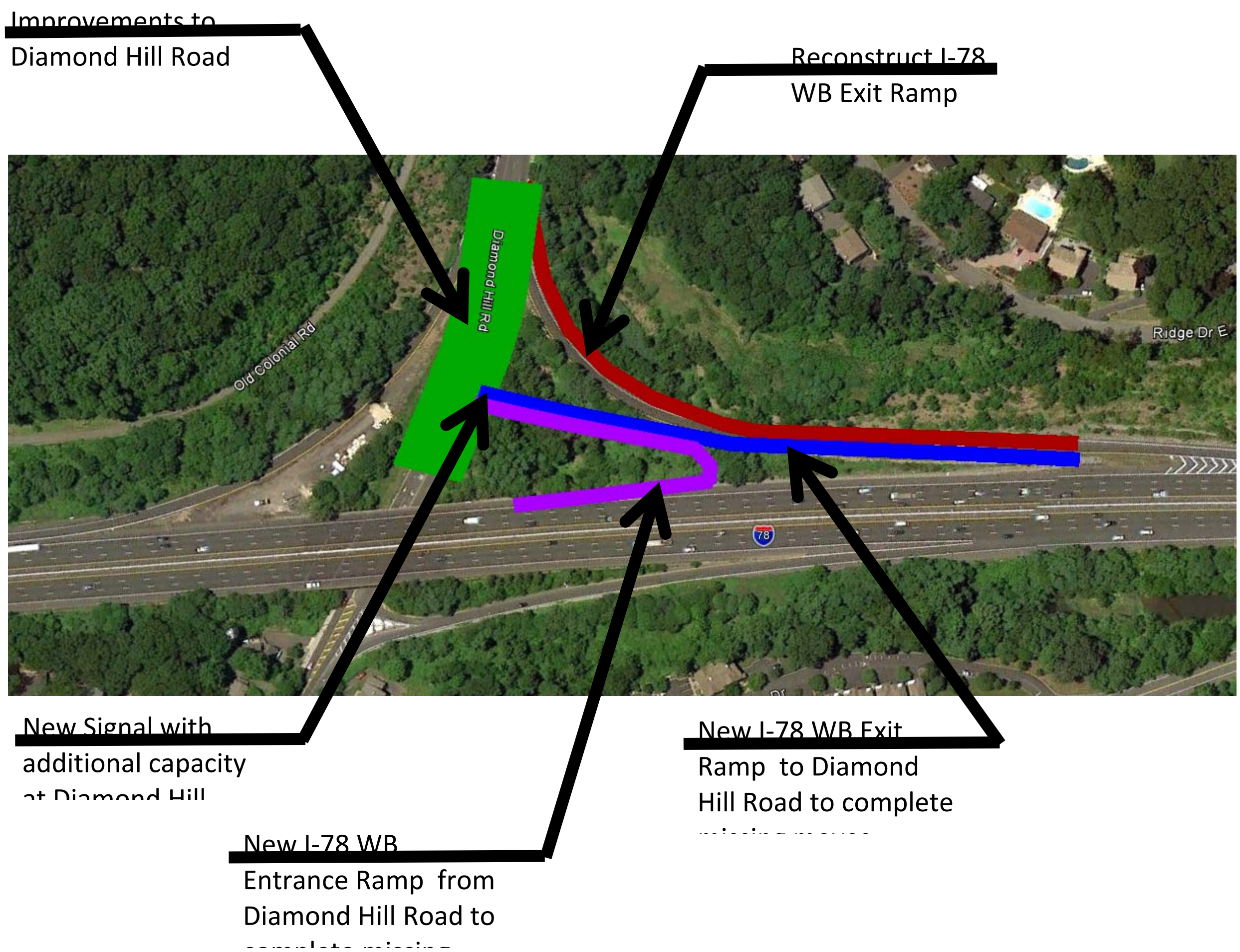


Interchange 71 provides I-95 traffic access to Broad Avenue in the northbound direction. The interchange does not provide Broad Avenue traffic access to I-95, or I-95 southbound traffic access to Broad Avenue. The team did not find a feasible option for completing the interchange due to the densely developed area as well as the parkland adjacent to I-95. Instead, the team developed a cost estimate for roadway improvements from Interchange 71 to Interchange 70 at Fort Lee Road. The improvements would include widening Fort Lee Road and Broad Avenue, and improving the signalized intersection at Broad Avenue and Fort Lee Road to accommodate the additional capacity required for improved traffic flow.

8. I-676 and CR 537 – Interchange 5

Interchange 5 provides I-676 traffic access to CR 537. The interchange does not provide Route 537 eastbound and westbound traffic access to I-676 northbound. The team did not find a feasible option for completing this interchange. In reviewing the existing infrastructure surrounding this interchange, the team also did not find a feasible option to be developed within the scope of this study. Therefore, the team used Option B, one-size-fits-all, for the construction cost estimate for this interchange.

9. I-78 and Diamond Hill Road (CR 655) – Interchange 43



Interchange 43 provides I-78 traffic access to Diamond Hill Road (CR 655). The interchange does not provide I-78 westbound traffic access to CR 655 southbound, or CR 655 northbound traffic access to I-78 westbound. For this study, the team considered the following improvements to complete interchange 43:

1. Reconstruct the I-78 westbound exit ramp in a new alignment to provide room for new ramps
2. Construct new I-78 entrance and exit ramps to complete the missing moves
3. Widen CR 655 to accommodate traffic flow associated with completed moves
4. Construct a new signalized intersection at CR 655 to control flow of traffic at the new interchange moves

5. Construct retaining walls to accommodate grade differentials between the three new ramps

10. I-295 and State Route 33 – Interchange 63

Interchange 63 provides I-295 traffic access to State Route 33. The interchange does not provide I-295 southbound traffic access to Route 33 eastbound, or Route 33 eastbound and westbound traffic access to I-295 northbound. The team did not find a feasible option for completing this interchange. In reviewing the existing infrastructure surrounding this interchange, the team also did not find a feasible option to be developed within the scope of this study. Therefore, the team used Option B, one-size-fits-all, for the construction cost estimate for this interchange.

4.5.3 Validation of Results

The team compared the results of the cost estimate performed by the team on the I-78 and Diamond Hill Road interchange with the results of an analysis on the same interchange by a consultant working for NJDOT[8]. The report indicates that various alternatives were reviewed by the consultant, including an alternative that closely resembles the alternative identified by the research team. Therefore, the team compared the alternative developed by the consultant with the work performed. The team also reviewed the modified preferred alternative for the project, as identified by NJDOT personnel.

The consultant's analysis included a total of seven alternatives, including 4A and 4B below. These alternatives were developed following NJDEP-requested modifications that eventually led to a modified "preferred alternative" list. The study included cost estimates for all six alternatives. These estimates are tabulated in Table 17.

Table 17. I-78 Interchange 43 Alternative Analysis Cost Estimates[9]

Alternative	Description	Cost Estimate
1	Stop-Controlled Intersection	$15,000,000
2	Collector-Distributor Road	$40,000,000
3	Forward Loop-Ramp WDS and Northbound Left-Turn Lane	$50,000,000
4	Loop-Ramp DNW and Underpass WDS	$25,000,000
4A	Ramp DNW on a Structure	$33,500,000
4B	Channel Relocation	$25,300,000
5	Roundabout	$35,000,000

[8] "NJDEP Individual Freshwater Wetlands and Open Water Fill Permit, Route I-78 at Diamond Hill Road Interchange Improvements", Dewberry – Goodkind, Inc., August 2006

[9] "NJDEP Individual Freshwater Wetlands and Open Water Fill Permit, Route I-78 at Diamond Hill Road Interchange Improvements", Dewberry – Goodkind, Inc., August 2006

The alternative most closely resembling the work performed by the team is Alternative 1, stop controlled intersection. Figure 10 shows the developed plan for this alternative. The plan shows the proposed realignment of the I-78 westbound exit ramp with the new left-turn option for Diamond Hill Road southbound. It also shows the new I-78 westbound entrance ramp.

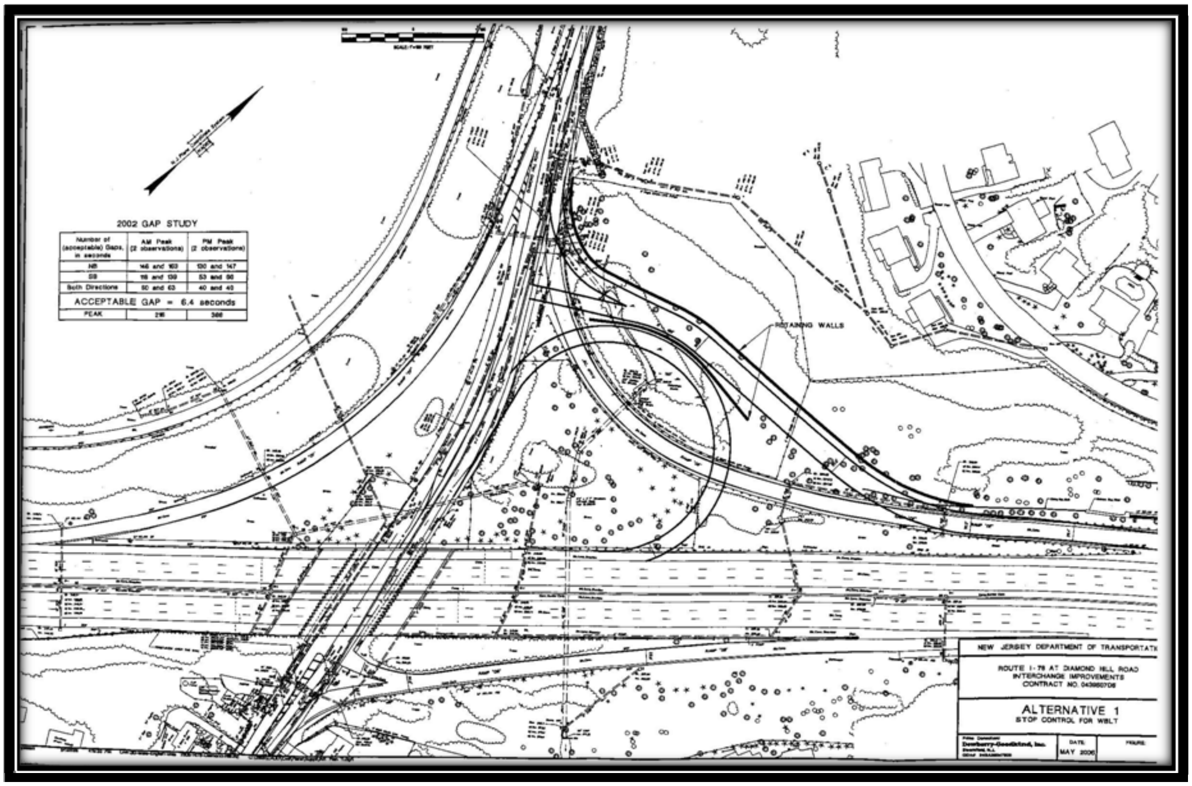


Figure 10. Alternative 1: Stop Controlled Intersection

The description provided by the consultant indicates several differences between the team's cursory review and the consultant's in-depth, comprehensive review of this alternative, which were not included due to the limited scope of our study. In particular, the differences are as follows:

1. The consultant mitigated the cut into the existing rock slope at the north side of the I-78 westbound exit ramp (identified as ramp DE) by proposing a 150-foot retaining wall.

2. The consultant identified the need for a second wall between the I-78 westbound exit ramp and the new I-78 westbound entrance ramp to account for grade differentials in roadway profiles.

3. The consultant ruled out a signalized intersection due to the steep grades along the approaches and the reduced line of sight from drivers to the signal as a result of the I-78 overpass.

4. The consultant verified that an unnamed tributary to Blue Brook flows through the existing interchange. As a result, the consultant proposed various improvements to accommodate the tributary.

5. The consultant suggested that a waiver from NJDEP groundwater recharge regulations should be pursued. In lieu of this waiver, there would be a need to construct bio-retention basins to meet regulations. This would require ROW takings and easements.

6. The consultant identified a sanitary sewer system that would need to be relocated.

The consultant's estimated construction costs for this alternative was $15 million. The estimate is between the $5 million (Option A) and $24 million (Option B) derived using the cost estimating procedure. The difference may be attributed to the high costs associated with rock excavation, additional retaining walls, stormwater sewer system improvements, and utility relocations. In particular, Option A uses estimated figures that do not account for construction of new roadways on steep grades, requiring heavy excavation, including rock excavation.

A design option considered in the study for this interchange matches closely one of the alternatives, although not the preferred alternative identified by the State and the consultant. Instead, the State indicated that it preferred Alternative 4b to any other proposed alternatives. The cost estimate for this alternative was $25 million, which compares favorably with the one-size-fits-all estimate. It should be noted that the alternative includes many of the aspects identified in the first alternative, as well as a new underpass for the I-78 westbound exit ramp tying to Diamond Hill Road southbound.

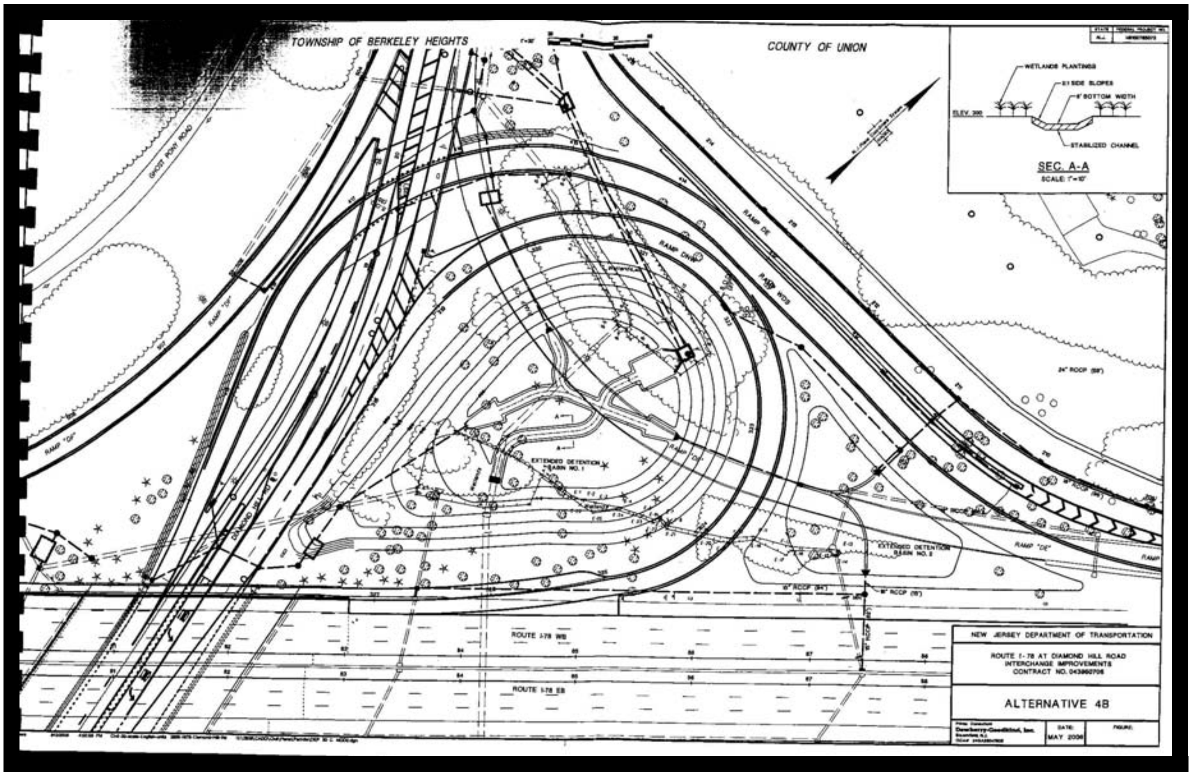


Figure 11. Alternative 4B: Channel Relocation

4.6 Benefit/Cost Analysis Calculation Methodology

4.6.1 <u>Annualizing Benefits and Costs</u>

The merit of each interchange improvement is determined based on the **benefit/cost (B/C) ratio** associated with the improvement. In this context, the **Cost** in the B/C formula refers to the construction cost of each improvement. The **Benefit** in the B/C formula refers to the difference between the road users' cost if the improvement is not implemented ("No-build" scenario) and road users' cost with full implementation of the improvement ("Build" scenario)[10].

The B/C ratio is usually calculated with respect to the present value or annualized value of the total benefits and costs. In this study, for the purpose of calculating the B/C ratio for each interchange improvement, the corresponding benefits and costs were

[10] "***No-build***" or "***Baseline***" scenario assumes that the interchange **will not be upgraded**. "***Build***" scenario assumes that the interchange **will be upgraded** by completing all "missing movements".

annualized, yielding the **average annual benefits and costs** associated with the interchange improvement.

As explained in previous sections, the road users' costs are calculated as annual estimates for model years 2010 and 2035. To annualize the benefits and costs during this period, the following assumptions are made:

1. Road users' cost are proportional to the growth in the regional traffic demand;
2. The regional traffic demand between years 2010 and 2035 is growing at a constant annual rate;
3. The user benefits in any given year during this period of time are equivalent to the difference between the road users' cost estimated for the "No-build" and "Build" scenario.

With this in mind, one can first use the formula for **Geometric Series of Cash Flows** to calculate the **Present Value** of the cumulative road users' cost during a given analysis period. This formula describes the case when a cash flow increases (or decreases) at a fixed rate from one time period to the next, as shown in Figure 12. This is equivalent to the assumption made about relative change in road users' cost from one year to the next. If C_t denotes the cumulative annual road users' cost at the end of annual period t, j denotes the relative change in the road users' cost from one year to the next, and n denotes the number of years in the analysis period, then:

$$C_t = C_{t-1} \times (1 + j), \quad t = 2, 3, \ldots\ldots, n.$$

or: (10)

$$C_t = C_1 \times (1 + j)^{t-1}, \quad t = 2, 3, \ldots\ldots, n.$$

The present value of the geometric series of annual road users' cost (P) over n annual periods can be calculated using the following equation[11]:

[11] More on time value of money and cash flow discounting formulas can be found in "Principles of Engineering Economic Analysis", by John A. White, Kenneth E. Case, and David B. Pratt, 5th Edition (2009), Wiley.

$$P = \begin{cases} C_1 \times \left[\dfrac{1 - \dfrac{(1+j)^n}{(1+i)^n}}{i - j} \right] & , i \neq j \\ \dfrac{n \times C_1}{1+i} & , i = j \end{cases} \tag{11}$$

where *i* denotes the annual interest rate.

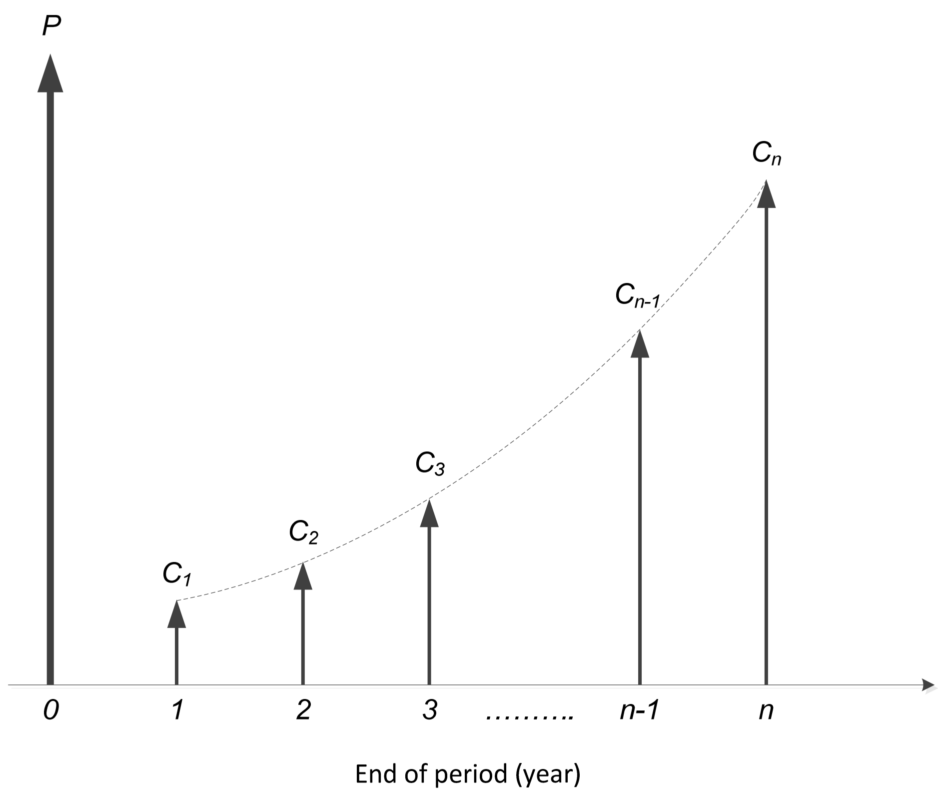


Figure 12. Diagram of the geometric series of annual costs

The **average annual road users' cost** (denoted as C^A) can then be calculated by multiplying the present value P by the **Capital Recovery Factor of a Uniform Series** formula, usually denoted as *(A|P,i,n)*:

$$A|P,i,n = \frac{i \times (1+i)^n}{(1+i)^n - 1} \tag{12}$$

$$\Rightarrow C^A = P \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \tag{13}$$

Replacing the variable *P* in Equation 13 with the expression for present value of the geometric series (given in Equation 11) yields:

$$\Rightarrow C^A = C_1 \times \left[\frac{1 - \frac{(1+j)^n}{(1+i)^n}}{i - j}\right] \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \qquad , i \neq j$$

or (14)

$$\Rightarrow C^A = \frac{n \times C_1}{1+i} \times \frac{i \times (1+i)^n}{(1+i)^n - 1} \qquad , i = j$$

If this procedure was used to calculate average annual road users' cost for the "No-build" and "Build" scenarios (denoted as C^A_{NB} and C^A_B respectively), then the **average annual user benefit B^A** can be calculated as:

$$B^A = C^A_{NB} - C^A_B \qquad (15)$$

The construction cost is usually estimated as a present value, so it can also be annualized using ($A|P,i,n$). Dividing B^A by the annualized construction cost of the improvement gives the **B/C ratio** used in determining cost-effectiveness of the improvement.

4.6.2 Sample Calculation

The calculation of the B/C ratio for an interchange improvement in this study is illustrated using a numerical example of I-80 Interchange 53 (at NJ Route 23). Before proceeding with the calculation, it is necessary to determine the time period over which the benefits and costs of each improvement will be considered. The NJDOT and MPO stakeholders collaborating on this study were consulted to determine the most appropriate analysis period. It was determined that y**ear 2015 was the earliest feasible year** any of the analyzed improvements can become operational. The stakeholders also agreed that the service life of new infrastructure can be considered to be between 20 and 25 years, assuming that reconstruction or capital maintenance would be required after this period of time. With this in mind, and given the availability of travel forecast data, the B/C analysis was conducted for a **21-year period of performance** starting from the **beginning of 2015** and concluding at the **end of 2035**.

As explained earlier, the road users' costs are calculated as annual estimates for model years 2010 and 2035 using the outputs from the regional travel demand models s. To calculate average annual road users' cost for the period 2015-2035, it is necessary to first calculate the users' cost in year 2015 (equivalent to C_1 in Equation 14 for geometric series of cash flows). The road users' cost in 2015 is estimated by applying geometric extrapolation of road users' costs between model years 2010 and 2035 for each cost category (i.e., passenger travel time, truck operating cost, air pollution mitigation, and fuel consumption) for both the "Baseline" ("No-build") and "Build" scenarios. The following is the formula for calculating estimated annual road users' cost in any given year between the model years 2010 and 2035 using geometric extrapolation:

$$C_{t,S} = C_{t_0,S} \times (1 + j_S)^{(t-t_0)} \tag{16}$$

where:

$C_{t,S}$ = road users' cost in year t and scenario S;

t_0 = model year 2010;

S = Scenario ("*NB*" for "No-build" and "*B*" for "Build" scenario);

j_S = relative annual rate of change in road users' cost in scenario S between model years 2010 and 2035, calculated using the following formula:

$$j_S = \left(\frac{C_{2035,S}}{C_{2010,S}}\right)^{\frac{1}{(2035-2010)}} - 1 = \left(\frac{C_{2035,S}}{C_{2010,S}}\right)^{\frac{1}{25}} - 1 \tag{17}$$

In the numerical example, the cost of travel time, as a component of the road users' cost, is calculated for the No-build and Build scenarios in 2010 and 2035 by summarizing the outputs of the travel demand models:

$C_{2010,NB}$ = \$31,769.76 (million) $C_{2010,B}$ = \$31,766.36 (million)

$C_{2035,NB}$ = \$43,021.92 (million) $C_{2035,B}$ = \$42,970.17 (million)

Then,

$$j_{NB} = \left(\frac{43{,}021.92}{31{,}769.76}\right)^{\frac{1}{25}} - 1 = 1.220\%$$
$$j_B = \left(\frac{42{,}970.17}{31{,}766.36}\right)^{\frac{1}{25}} - 1 = 1.216\% \tag{18}$$

and:

$$C_{2015,NB} = C_{2010,NB} \times (1 + 0.01220)^{(2015-2010)} = \$31,769.76 \times (1 + 0.01220)^{5} = \$33,755.58 \text{ (million)} \quad (19)$$

$$C_{2015,B} = C_{2010,B} \times (1 + 0.01216)^{(2015-2010)} = \$31,766.36 \times (1 + 0.01216)^{5} = \$33,745.30 \quad (20)$$

The average annual cost of travel time for both "Build" and "No-build" scenarios can be now calculated using Equation 14, where C_1 is replaced by $C_{2015,B}$ and $C_{2015,NB}$ (from Equations 19 and 20), and j is replaced by j_B and j_{NB} (from Equation 18) for the "Build" and "No-build" scenarios respectively. The analysis period n is 21 years, assuming that year 2015 is the first year in which the improvement would be operational. The interest rate i applied in the calculation is prescribed by the Office of Management and Budget for analyzing cost-effectiveness of public investments[12]. Given the 21-year period of analysis in this study, the Real Interest Rate on Treasury Notes and Bonds with the maturity of 20 years was used (prescribed rate for CY2012 used in this calculation was 1.7 percent). Applying the formula for C^A to the "No-build" scenario yields:

$$\Rightarrow C_{NB}^{A} = C_{2015,NB} \times \left[\frac{1 - \frac{(1+j_{NB})^n}{(1+i)^n}}{i - j_{NB}} \right] \times \frac{i \times (1+i)^n}{(1+i)^n - 1}$$

$$\Rightarrow C_{NB}^{A} = \$33,755.58 \times \left[\frac{1 - \frac{(1+0.0122)^{21}}{(1+0.017)^{21}}}{0.017 - 0.0122} \right] \times \frac{0.017 \times (1+0.017)^{21}}{(1+0.017)^{21} - 1} =$$

$$= \$37,925.12 \text{ (million)} \quad (21)$$

Similarly, applying the formula for C^A to the "Build" scenario yields:

$$\Rightarrow C_{B}^{A} = \$33,745.30 \times \left[\frac{1 - \frac{(1+0.01216)^{21}}{(1+0.017)^{21}}}{0.017 - 0.01216} \right] \times \frac{0.017 \times (1+0.017)^{21}}{(1+0.017)^{21} - 1}$$

$$= \$37,897.83 \text{ (million)} \quad (22)$$

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[12] 2012 Discount Rates for OMB Circular No. A-94,

Finally, the annual benefit of the improvement with respect to savings in travel time can be calculated as a difference between annual costs in “Build” and “No-build” scenarios, as follows:

$$B^A = C^A_{NB} - C^A_B = \$37{,}925.12 - \$37{,}897.83 = \$27.29 \text{ (million)} \quad (23)$$

As explained in section 3.5, the construction costs are estimated in current dollars, assuming the total cost of construction is expensed instantaneously at the time the improvement becomes operational (i.e., at the beginning of year 2015). Based on the analysis of needed improvements at I-80 Interchange 53, the total cost of construction is estimated at $5.56 million. These costs are annualized over the period 2015-2035 by applying the **capital recovery discounting formula** for the period of 21 years and the above mentioned interest rate of 1.7 percent. This calculation yields an annual cost of construction of $316,955.

Clearly, the cost-effectiveness of this investment is confirmed by comparing the cost of construction to the benefits it generates by reducing motorist travel times. This is reflected in the B/C ratio:

$$B/C\ Ratio = \frac{\$27{,}290{,}000}{\$316{,}955} = 86.10 \quad (24)$$

4.6.3 Benefit/Cost Analysis Results

The B/C analysis of interchange upgrades for 10 selected partial interchanges was conducted. These interchanges were selected for the analysis in consultation with the NJDOT and MPO stakeholders collaborating on this study as those that ranked highest in the screening process (see Table 4).

With respect to the model developed, normally a B/C ratio greater than 1 indicates that the investment in the upgrade is cost-effective (i.e., user benefits exceed the construction costs). Likewise a negative B/C ratio would normally indicate that the improvement actually does not provide any user benefit; on the contrary, in these instances the outputs from the regional travel demand models indicate that overall users’ cost increases after the partial interchange is upgraded. While it may seem counterintuitive, this type of result is possible when aggregating effects of individual transportation capital project across a regional network using the outputs from demand models that apply user equilibrium traffic. Such an outcome can be readily explained by Braess's paradox, which states that adding extra capacity to a transportation network, when the drivers selfishly choose their route to minimize their individual travel time or cost (equivalent to user equilibrium assignment), can in some cases reduce individual performance (i.e. increase the travel times or costs). The final effect of this paradox is that an extension (or widening) of the road network may cause a redistribution of the existing traffic that results in longer overall travel times (and/or associated user costs). This phenomenon is explained in greater detail in Sheffi (1985).

The results show that six interchanges have positive B/C ratios. Certainly, the upgrades at these interchanges can be considered high priority for implementation, considering the results of the B/C analysis.

Four of the analyzed interchanges have negative B/C ratios, indicating that improvements may not be beneficial from the regional users' cost perspective. However, these results are not "all inclusive" and do not take into account all quantifiable and non-quantifiable benefits (e.g., improves access to hospitals, parks and recreation facilities, employment centers, etc.).

The B/C modeling effort was performed based on a single variation analysis, and each improvement was modeled without considering other system changes that may contribute to more positive effects of each individual interchange upgrade. These kinds of groupings/combinations of projects may result in a change in the B/C results, and should not be excluded from further considerations and studies.

Although only 10 interchanges were selected for the B/C analysis (not enough to draw a definitive statistical correlation) the results did have some alignment with the screening ranking. Due to Braess's paradox, questions over whether user equilibrium assignment is ever achieved, and the single variation analysis; the research team did not feel it was appropriate to rank any of the analyzed interchange upgrades as not cost-effective, even with negative calculated B/C ratios. Therefore the evaluated interchange upgrade projects with a positive B/C analysis are labeled as "high priority." and those with a negative B/C ratio as "medium priority." Furthermore, in comparing the B/C analysis to the screening process (as well as the sensitivity analysis); from a simplistic viewpoint in the future the results of the screening process can be used instead of the full B/C analysis.

The results of the study are based on the evaluation methodology developed in collaboration with the NJDOT and Metropolitan Planning Organizations (MPOs). Both the screening analysis and the B/C analysis results are meant to provide guidance to constituents in identifying priority locations for further analysis and possible inclusion as problem statements into NJDOT's project development process. Any accepted problem statement would undergo a full planning/scoping study as part of the Concept Development phase, prior to which would need FHWA approval before moving into the design phase. The prioritizations presented in Table 18 provide a starting point for the NJDOT and MPOs to move projects forward.

5 CONCLUSIONS

The results of the study are based on the evaluation methodology developed in collaboration with the NJDOT and MPOs. The results are meant to provide guidance to constituents in identifying priority projects for future review and possible inclusion into the capital program. A full planning/scoping study would be required for each project prior to making any final determination. The criteria used for evaluation of interchange improvements in this study included:

- Travel time: overall savings in travel time on the regional network (and corresponding cost) resulting from the improvement.
- Fuel consumption: expected reduction due to improved ability of vehicles to operate in more efficient regimes on highways.
- Vehicle emissions: including pollutants NOx, HC, and CO, as well as reduction in carbon footprint.

The main source of data for this analysis are regional travel demand forecasting models that estimate the changes in VMT and VHT on each link of the regional network, resulting from the partial interchange improvements.

These results are not "all inclusive" and do not take into account non-quantifiable benefits. Any improvement that increases access has an inherent quality of life benefit (e.g., improves access to hospitals, parks and recreation facilities, employment centers, etc.); however this benefit may only have quantifiable VMT benefit for a relatively small population (such as a local community), and therefore, when considering the larger regional network, it may not result in an overall favorable B/C ratio. This does not mean that the project shouldn't be considered; but that constituents should take into account non-quantifiable factors when considering what projects to move forward.

As the states' infrastructure continues to age and traffic volumes increase in one of the most densely populated states, it's important to recognize that there are competing financial priorities. Maintaining "state of good repair" is of primary concern and decisions regarding new construction projects need to be carefully considered. In developing a methodology for quantitative evaluation of upgrading partial interchanges, the final results have been grouped into categories to provide clear guidance. The evaluated interchange upgrade projects with a positive B/C analysis are labeled as "high priority." and those with a negative B/C ratio as "medium priority." The prioritizations presented in Table 18 provide a starting point for the NJDOT and MPOs to move projects forward.

Table 18. Prioritization Table for Full Planning/Scoping Study (select ten analyzed partial interchanges)

Rank Based on Prescreening Methodology	Priority Based on Cost Benefit Analysis	Interchange
3	High Priority	I-80 Interchange 53 (AT RT 23)
1	High Priority	I-78 Interchange 54 (at Winans Ave)
11	High Priority	I-95 Interchange 71 (at Broad Ave)
16	High Priority	I-676 Interchange 5 (at CR 537)
6	High Priority	I-287 Interchange 2 (at NJ 27)
7	High Priority	I-80 Interchange 55 (at NJ 62)
2	Medium Priority	I-80 Interchange 64/64A (at NJ 17)
10	Medium Priority	I-78 Interchanges 44 & 45 (at CR 527)
25	Medium Priority	I-295 Interchange 63 (at NJ 33)
12	Medium Priority	I-78 Interchange 43 (at CR 655)

The research team did not feel it was appropriate to rank any of the analyzed interchange upgrades as low priority or not cost-effective, even with negative calculated B/C ratios. The reason is that the modeling effort was performed based on a single variation analysis, and each improvement was modeled without considering other system changes that may contribute to more positive effects of each individual interchange upgrade. These kinds of groupings/combinations of projects may result in a change in the B/C results, and should not be excluded from further considerations and studies. This will be of particular interest at those locations where individual improvements are in close proximity to each other. To better understand how one or more additional system improvements would affect the results, this would require an extensive permutation development and modeling of each variation, which was not within the scope of this study.

Although only 10 interchanges were selected for the B/C analysis (not enough to draw a definitive statistical correlation) the results did have some alignment with the screening ranking. Furthermore, due to Braess's paradox - questions over whether user equilibrium assignment is ever achieved and the single variation analysis; as an alternative to conducting the B/C analysis in the future the results of the screening process can be reliably used to generate ranking lists.

The resultant final list, or prioritized list of partial interchanges are not prescriptive, but are meant to provide guidance to constituents in identifying priority locations for further analysis and possible inclusion as problem statements into NJDOT’s project development process. Partial interchanges that scored higher in the screening analysis (scores and ranking of evaluated partial interchanges are shown in Table 4) are considered potential candidate interchanges for future improvements. Once a decision is made to investigate interchange locations for project development, NJDOT’s interagency Congestion Management Committee would take the lead as part of the congestion relief problem statement development process.

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