A Preliminary Examination of Data Envelopment Analysis for Prioritizing Improvements of a Set of Independent Four Way Signalized Intersections in a Region

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(ABSTRACT)

Evaluation of critical transportation infrastructure and their operation is vital for continuous evolution to meet the growing needs of the society with time. The current practice of evaluating signalized intersections has two steps. The first is to determine the level of service at which the intersection is performing. Level of Service (LOS) is based on the average delay per vehicle that gets past the particular intersection under consideration. The second step is to do a capacity analysis. This considers the number of lanes and other infrastructure related factors and also includes the influence of the control strategies.

The above-described procedure evaluates any one intersection at a time. It is necessary to compare and rank a given set of intersections for planning purposes such as choosing the sites for improvements.

The research work presented in this thesis demonstrates how Data Envelopment Analysis (DEA) can be used as a tool to achieve the purpose of comparing and ranking a given set of comparable intersections. This study elaborates on various ways of representing different characteristics of an intersection. The demonstration has been restricted to four way signalized intersections.

The intersections that were used for demonstration as part of this research were created in a restricted random fashion by simulation.

Dedication

I dedicate this work to my parents and all of my past and present teachers

Acknowledgements

I thank Dr. Teodorovic, my committee chair for his support and guidance through out my graduate studies. I also would like to use this opportunity to thank my committee member Dr. Triantis for having made this possible by their support and guidance. I am very much thankful to Dr. Collura for having made this research possible by his support and having provided me with support, guidance and vision.

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List of Abbreviations

1. DEA – Data Envelopment Analysis
2. LOS – Level of Service
3. DMU – Decision Making Unit
4. Intersection – Roadway intersection
5. Four way Intersection – Roadway intersection with four approaches
6. MOE – Measure of Effectiveness
7. FHWA – Federal Highway Administration

Chapter1. Introduction

Evaluation of critical transportation infrastructure and their operation is vital for continuous evolution to meet the growing transportation needs of the society with time. The current practice of evaluating signalized intersections has two steps. The first is to determine the level of service at which the intersection is performing. Level of Service (LOS) is based on the average delay per vehicle that gets past the particular intersection under consideration. The second step is to do a capacity analysis. This considers the number of lanes and other infrastructure related factors and also includes the influence of the control strategies.

The above-described procedure evaluates any one intersection at a time. It is necessary to compare and rank a given set of intersections for planning purposes such as choosing the sites for improvements. A method for this purpose was developed in this study. This method derives from a systems engineering approach popularly known as Data Envelopment Analysis (DEA). More details on this approach is provided in the later sections of this chapter and the next chapter. The next section spells out the specific objectives of this research.

1.1 Research Objectives

It is very important to define the objectives of any research at the outset to recognize the quality of the product at the end of the research. The following were identified and agreed upon as the objectives of this research study.

1. To formulate a framework for comparing and ranking a set of roadway intersections based on technical efficiency for better planning and decision-making. Technical efficiency is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs.
2. To demonstrate the use of formulated framework by using a data set of more than 50 four ways signalized intersections. This demonstration will use the data created by simulation.

3. To develop indices that would help to represent the characteristics of an intersection mathematically.
4. To validate the framework for four way signalized intersections by analyzing the results and comparing them to expert opinions.
5. To provide a repository of problem areas that describes further possible research in this area.

1.2 Research Motivation

The performance of a roadway intersection is predominantly measured as level of service (LOS) in terms of the amount of average delay that is caused to vehicles to get through that particular intersection and may be supplemented by a process known as capacity analysis. In other words, Average delay per vehicle is the primary measure for determining the level of service at signalized intersections[1]. Based on the average delay per vehicle, an alphabet from the set {A, B, C, D, E, F} is used to represent the level of service at which the intersection is performing.

This type of evaluation of an Intersection is good enough when the purpose is to know how long on an average it will take for a vehicle to get through the intersection. To know how effective the intersection is performing with respect to the infrastructure and control strategies, Level of Service (LOS) may not be the best measure of effectiveness (MOE).

Since technical efficiency considers the aspect of capacity provided and the average delay per vehicle perception, there was a potential to use the concept of technical efficiency for the above objectives.

Technical efficiency is defined as the ratio of the weighted sum of inputs to the weighted sum of outputs as mentioned earlier. To measure the technical efficiency of an entity, an analogy of that entity to a typical production unit needs to be established and appropriate inputs and outputs should also be identified.

Finding out how effective an intersection is performing, is of great importance for budget allocation purposes and selection of competing alternatives for proposed infrastructure improvements. The concept of technical efficiency fit into the role of an evaluation tool that takes all the aspects of intersection into consideration.

The developed tool was also desired to have the capacity to compare and rank a set of intersections. The search of a tool based on the concept of technical efficiency with the ability to compare and rank a set of comparable intersections led to the examination of the potential of Data Envelopment Analysis for this purpose.

1.3 Background

There are hundreds of signalized intersections in every single jurisdiction and they are geographically dispersed. For these geographically disperse units, delay per vehicle, the objective performance measure used by all agencies has few deficiencies as a tool to be used for choosing competing alternatives.

Let us consider two intersections (A and B) with the same level of service (For Example, LOS A s). This just means that the average delay per vehicle for both these intersections are very similar (i.e. the average delay per vehicle for both the intersections is less than 10 seconds as defined by the Highway capacity Manual 2000 [HCM 2000]). But the technical efficiency of intersection A may be 0.75 and intersection B may have an efficiency of 0.5. This difference in the technical efficiency means that intersection A is operating with lesser usage of resources than intersection B while serving the vehicles getting through the respective intersections at the same level. The developed tool will help find these differences in the set of intersection that will in turn direct the improvements and set performance goals to intersection B.

Let us consider another situation. There can be two intersections (A and B) that have very comparable technical efficiencies (Ex: in the range of 0.25 - 0.35). There is a very good possibility that the average delays caused per vehicle at these intersections are very different (Ex: 40 sec/Vehicle for one and 30sec/Vehicle for another). This different average delay per vehicle lists intersection A in LOS D and B in LOS E. While LOS D is considered to be operable E catches the attention of traffic engineers. This tool will again help identify these differences. By identifying this, B will be set a performance goal to achieve that of A.

The above-depicted two situations explain that average delay per vehicle alone cannot form the basis of evaluating the performance of intersections and the average delay per vehicle is an important parameter to be considered in the process of comparison and evaluation. For these geographically disperse units (i.e. Intersections), the average delay per vehicle is highly dependent on parameters such as the traffic on each approaches, the percentage of turning vehicles on each approaches, appropriateness of phasing system, appropriateness of time slices for each movement, total cycle time, distance from the nearest intersection, number of lanes for each approach and movement. Other factors such as average number of stops per vehicle need to be considered. It becomes of great significance to include as many significant factors that are listed above as possible whenever there is an effort to compare intersections. The inclusion of any of these factors requires judgment from the part of the modeler. There may also policies of the specific region that influence the inclusion or exclusion of these parameters.

The arguments presented above support the notion that myopic focus on average delay per vehicle can induce unwanted behavior in decision making (planning) for improvements in the intersections. If comparisons between units are made merely on this parameter, Intersections with very low volume of traffic will always have a positive bias to be shown as efficient intersections while the ones with higher volumes may always be shown inefficient. This situation leads to a scenario where the intersections with low volume may never get any improvements. But the intersections with low volumes may not be operating at a low technical efficiency and may need minimal improvements to have a performance goal to be achieved.

Converting all the identified inputs and outputs to a particular unit such as in dollars and then taking the ratio can achieve calculating technical efficiencies. This leads to the area of combining many disparate measures of performance into an overall assessment dollar value. it may not be very accurate to achieve an universal conversion factors related to how much of Intersection delay should be traded off for each unit of average stops per vehicle. This is overcome by DEA as it treats the inputs and outputs of different units as they are and does not do any conversion.

Data Envelopment analysis is a method that shows promise to address all of the problems discussed above. Formally, DEA is a linear programming technique for measuring the relative efficiency of decision-making units (DMUs) where each DMU has a multitude of desired outputs or needed inputs. In practical terms, one use of DEA is as a measurement tool for multisite organizations when a single overall measure, such as average delay per vehicle, is not sufficient. DEA combines numerous relevant outputs and inputs into a single number that represents productivity, or "efficiency."

DEA is a well-known and established technique among some researchers in operations research. Between the inception of DEA in 1978 by Charnes, Cooper, and Rhodes, and 1992, over 470 articles were written concerning DEA (Seiford 1994), and the pace appears to have accelerated since that time. Yet, it is still sufficiently esoteric that it appears in few textbooks, and tutorials explaining the basics of the technique are still deemed necessary at scientific conferences of generic nature (Seiford and Cooper 1997).

Here, the attempt is not to extend the methodology of DEA. Rather, a guide for practice is intended. The contention is that DEA can be a highly useful tool for planning in transportation engineering practices, but one has to be aware that DEA is context sensitive and we need to use discretion in applying. That is, the rules for model choice, variable choice, and results interpretation change depending upon the managerial purpose. The purpose here is to generate a framework to evaluate the performance of a set of isolated intersections, which can be customized and elaborated to the needs and legal liabilities, land use policies, long term and short term plans in effect of the decision making transportation agency and the directives of Federal Highway Administration (FHWA).

1.4 Overview of proposed Methodology

In general, the conditions required to use DEA are that a number of DMUs (In this case, intersections) are attempting to accomplish roughly the same goals that there is some “goal diversity”. That is, there is more than one desirable goal and the goals cannot be compared in a straightforward fashion. In a technical sense, DEA measures only efficiency or productivity. DEA was developed for uses in the evaluation of nonprofit sector firms, but the use of DEA has been expanded in practice. DEA has been used in the non-profit sector to identify superior/inferior branches, to evaluate managerial performance, to allocate resources among branches, or to diagnose the determinants of successful/unsuccessful branches at various sites (Henderson 1989).

Early applications of DEA centered on multiple-site nonprofit organizations because of the multiple goals and goal diversity that exist in such environments. For example, the goals of an elementary school may include disparate elements such as student self-esteem in addition to reading and arithmetic ability (Charnes, Cooper, and Rhodes 1981). As discussed earlier, goal diversity also applies in the for-profit sector. Accordingly, DEA has been applied to for-profit activities such as nursing homes (Fizel and Nunnikhoven 1993), restaurants (Banker and Morey 1993), and insurance agencies (Mahajan 1991).

At heart, DEA is about measuring the productivity of a unit, where productivity is defined as the ratio of produced outputs to consumed inputs. Measuring productivity is often a simple matter for many individual jobs, but can become complex for groups with multiple goals. For example, if bank teller 1 handles 190 transactions per day, where as teller 2 handles 270 transactions, teller 2 is more productive, ceteris paribus. If those tellers handle different types of transactions, the raw data is no longer sufficient. The transaction must be weighed according to the agreed standard time required per handling. If teller 1’s 190 transactions were judged to require 9 standard hours, whereas teller 2’s 270 transactions required only 7.5 hours, teller 1 would be considered more productive.

The same situation is faced with in many of the planning practices in traffic engineering. Let us Consider two intersections, one intersection can be causing just an average delay of 35 seconds per vehicle and the other intersection can be performing at 250 seconds per vehicle of average delay. If we looked at the v/c ratio of the left turning movements for the two major approaches, it could be 0.02 for the first Intersection and 0.78 for the other. Even though we don't have a commonly accepted conversion of left turns to through vehicles, one may try to do the conversion and see that the second intersection is performing at a better efficiency than the first one.

On a Decision Making Unit (DMU) level (Where a DMU is typically a distinct Intersection), however, evaluating productivity is not always as simple because of the multiple strategic directives that cannot be combined in a single measure.

It is explained in chapter 2 and chapter 3 how DEA works, in great detail. To achieve the above stated objectives in section 1.1, the following methodology is followed.

A set of inputs and outputs that are the most important factors of the performance of an intersection are identified based on the influence of the factors on the performance of the intersection. The influence of these factors on the performance derived from the literature was used as the criteria combined with some technical reports with the collective wisdom of professionals. The next step was to represent these physical inputs and outputs identified in mathematical format. For this purpose, Indices were defined in such a fashion that the input indices follow the trend of higher inputs leading to higher good output and lesser bad output. This is explained in chapter 3 in detail.

Choosing a model comes next. There are very many ways in which any system can be modeled. Since there is no precedence for modeling a signalized intersection in DEA, a set of established DEA models were identified and used to meet the objectives of this modeling effort.

These indices representing inputs and outputs are to be calculated for each of these intersections. At this stage, the set of intersections (a chosen group of comparable isolated intersections) was modeled using the chosen DEA model.

Once the intersections were modeled in DEA, we had a measure of relative efficiency for all the intersections in our hands. We also obtain the peer groups of intersections and the performance goals for these peer groups. Considering this relative efficiency and the performance goals, one can determine what are the types of improvements required and how much of these improvements in terms of each input are required.

Another major contribution of this research is to scope the gaps in using DEA as an effective tool for transportation planning and list possible research areas that will help narrow the gap. The concern that would be addressed is what are the appropriate decisions that could be based on these results spewed out by DEA based models.

1.5 Organization of this document

Chapter 2 starts with an explanation on the traditional ways of measuring performance of intersections. It expands onto the applications of DEA for performance evaluation and the fundamental measures in efficiency measurement. It then presents the theoretical background on returns to scale and on the disposability of inputs and outputs in production, as these qualities of DEA are pertinent to this effort in this study. This section talks about few of the DEA models that are capable of modeling good and bad outputs. These are the potential models that may be used for four way signalized intersections as they also produce bad outputs in the form of delay for the vehicles getting through these intersections.

Chapter 3 presents the methodology proposed in this research by describing the indices and the model formulation for this effort. It also provides a brief overview of the data that will be used in illustrating the application of these types of formulations in transportation engineering decision-making.

Chapter 4 illustrates the results obtained from the modeling of isolated four way signalized intersections. The performance measure, peer group of intersections and the performance goals for each intersection is presented in this chapter. There is also discussion on what these results mean for the decision makers. This is achieved by illustrative examples.

Chapter 5 presents the conclusion of this research effort and makes recommendations for future research. The first section summarizes the research of this thesis. The second section describes the major contribution of this research and the third section outlines some recommendations for future research.

Finally, the appendix has the actual data sets, used in chapter 4 for the application of the models introduced in Chapter 3. The appendix also displays the programming code used to run the models in MS Excel Solver and Visual Basic for Excel.

Chapter 2. Review of Literature

This Chapter reviews procedures for the analysis of the capacity and level of service of four way signalized intersections. The signalized intersection is one of the most complex components in any traffic system. Signalized Intersection analysis must consider a wide variety of prevailing conditions including the amount and distribution of traffic movements, traffic composition, geometric characteristics, and details of intersection signalization.

2.1 Four way Signalized Intersections

Every transportation system is full of intersections to create an effective network of roadway facilities to move people and good from their origin to their destination in an efficient manner. A great number of these intersections are four way (i.e. they have four approaches) and signalized. They are typically the bottlenecks in most of the road networks. Operating these intersections at the best efficient manner as possible is very critical to efficient operation of road networks. The purpose of traffic signals at intersections is to allocate the time for the right of way of each movement in the most efficient manner ensuring the motorist safety and fairness to every user of the system.

Modern traffic signals allocate time in a variety of ways, from the simplest two phase pretimed mode to the most complex multi-phase actuated mode. There have not any research specific to applying any systems engineering techniques to compare and contrast a set of comparable isolated intersections.

The word “comparable” in this document used to mean the following. Comparable four way signalized intersections are the ones that have very similar properties listed below.

1. Pavement properties

2. Weather conditions through years
3. Inclination of the approaches with each other
4. Driver mix in terms of age, sex, familiarity of the location etc.
5. Speed limits of the approaches
6. Average visibility conditions
7. Vehicle mix in terms of the size of the vehicle
8. Control strategy in terms of pretimed, semi-actuated and fully actuated

A set of comparable intersections can be obtained by clumping intersections with similar neighborhoods together into one set. All of the above factors are similar and comparable if the neighborhoods of the intersections are similar.

2.2 Level of service (LOS) of Signalized Intersections

Signalized intersections are evaluated as an index defined as level of service. The level of service is measured as follows.

The following table to reproduces the HCM table that defined the level of service based on the control delay at signalized intersections.

Level of Service (LOS)	Control Delay Per Vehicle (in seconds)
A	≤10
B	>10 and ≤20
C	>20 and ≤35
D	>35 and ≤55
E	>55 and ≤80
F	>80

Table 2.1 Level of Service from Control Delay (Source: HCM 2000)

Capacity analysis is central to the estimation of level of service. Capacity analysis is explained below in detail. In the analysis of intersections, they are not as strongly correlated as they are for other facilities. For signalized intersections, the two are analyzed separately and are not related in a simple way to each other. It is critical though that both capacity and level of service must be fully considered to evaluate over all operation of a signalized intersection.

The following subsection elaborates on analyzing the capacity to evaluate the intersections.

2.3 Capacity Analysis for Signalized Intersections

A separate capacity is computed for each lane group approaching an intersection. A lane group is defined as one or more lanes that accommodate traffic and have a common stop line and capacity shared by all vehicles. An example of lane groups with the phasing system is shown below.

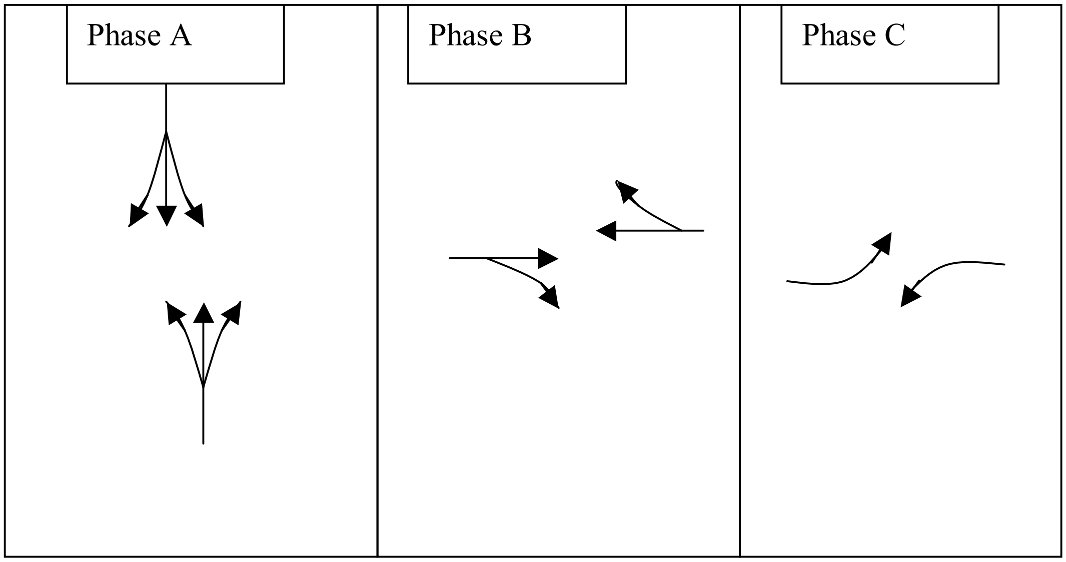

Figure 2.1 Signal Phasing

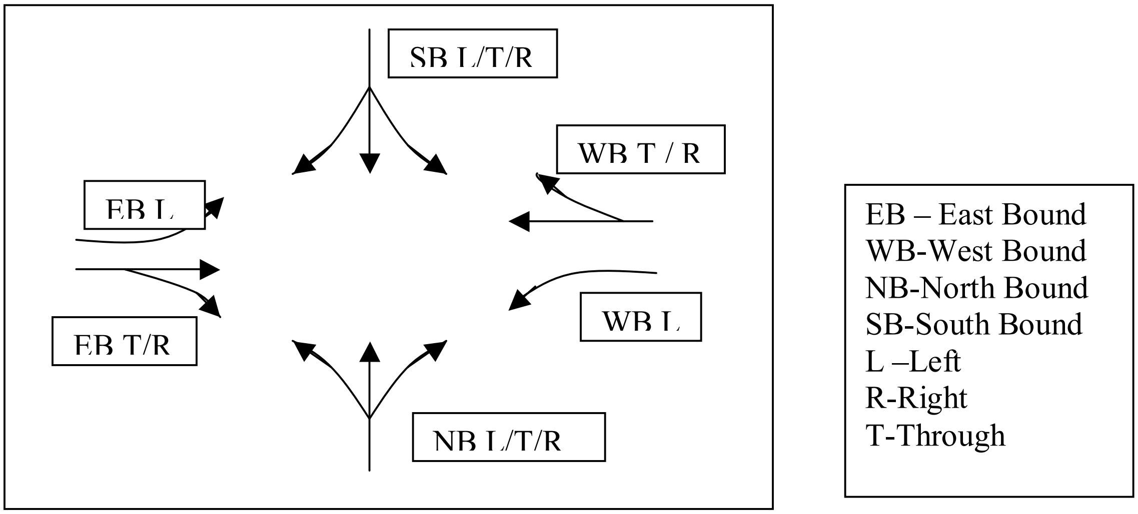

Figure 2.2 Lane Group

Each of the rectangular boxes above represent a lane group. There are 6 lane groups in the figure shown above.

Capacity analysis results in the computation of volume-to-capacity ratios (v/c) for each of these lane groups. The v/c ratio is the actual or projected rate of flow on a designated lane group during a 15 min interval divided by the capacity of the lane group. Although the capacity of the entire intersection is not defined, a composite v/c ratio for the sum of critical lane groups within the intersection is computed as an indication of the overall intersection sufficiency.

Level of service is based on the average delay per vehicle for various movements within the intersection. Although v/c ratio affects the average delay per vehicle, there are other parameters that more strongly affect it, such as length of green phases, cycle lengths, and others. Thus, for any given v/c, a range of delay values may result, and vice versa. For this reason both the capacity and level of service of the intersection must be carefully examined (2).

The v/c ratio is measure of whether or not the physical geometry and signal design provide sufficient capacity for the subject movements or movements. Delay is a measure of quality of service to motorists. Both must be analyzed fully to understand the anticipated operational characteristics of the intersection, and neither can be substituted for the other.

This fact makes comparing intersections a difficult task, as there are two measures by which the intersections are assessed. The method found here is one that combines both for comparison of various intersections.

2.4 DEA and Efficiency Measurement

Efficiency of any firm or production unit is traditionally measured by a score based on the ratio of output produced by the process divided by the input used up by the process. The traditional efficiency measurement can be shown as the equation below.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \qquad \textbf{(2.1)}$$

This measure of efficiency has its own drawbacks, some of which are described below.

i) Multiple inputs and outputs cannot be incorporated in this efficiency measurement. Multiple inputs and outputs may involve converting all of the inputs to one common unit (ex: dollar) and also outputs to one common unit. Such conversions may implicate bias into the data.

ii) Environmental effects due to the process cannot be incorporated in this model.

2.4.1 Technical Efficiency

As an improvement on the above-explained method of measuring efficiency, Farrell (1957) came up with a new measure of efficiency that considered all the inputs and outputs of a process.

This measure was defined in such a way so as to overcome the first drawback mentioned above, and to know how far "a given industry can be expected to increase its output by simply increasing its efficiency, without absorbing further resources."

This new measure of efficiency, termed as technical efficiency, is a score determined for each unit (Firm/Production unit) in the chosen group. The unit is analyzed within a group of comparable units and is evaluated by comparing it with some ideally performing unit (Pasupathy 2001). This ideally performing unit is found by one of the following means.

i) Theoretical - the entire production process is represented as a theoretical or “ideal” production function where the outputs produced by the process are expressed as a function of the inputs. This function provides the ideally performing unit and the expected performance for the subject unit by comparing the current performance of the subject unit to this ideal function.

ii) Empirical - unlike the theoretical approach where the units are compared to an ideal situation that is impossible to operationally achieve, the performance of a subject firm is determined by comparing it to a relative production combination obtained from the best practices of the peer units from the set of subject intersections. In this case, the units are compared to best practices that have been achieved already by another unit in the set.

There are two methods in which the empirical method can be implemented. As in eq. 2.1, the technical efficiency is measured by the ratio of outputs to inputs. In optimizing these efficiencies, outputs may be held constant while the inputs are minimized to maximize the technical efficiency (input oriented modeling). The second way to do this is to hold the inputs constant and maximize the outputs (output oriented modeling). These methods are explained with example scenarios such as multiple inputs firm (two inputs, one output) and multiple outputs firm (two outputs, one input).

2.4.2 Input Oriented Models

The following diagram describes this concept of input oriented model by an example of two inputs and one output firm. X_1 and X_2 are inputs and Y is the output of the firm. The QQ' represents the isoquant that is also the most efficient relative production combination (i.e. efficient production function"). Isoquant is the set of all points that are combination of inputs that produce the same amount of a specified output. Here it is assumed to be q.

In figure 2.3, the quantity q is assumed to be one. All the firms that are to be compared and normalized so that they produce the same amount of output quantity q using varying quantities of inputs X_1 and X_2 based on their production capabilities. Once this is done, all the production firms are plotted in the diagram to obtain a scatter plot.

The isoquant is then computed or estimated and is also included in the scatter plot. The efficient production function is defined in such a way that all the firms lie to the northeast of the isoquant. P is one such firm represented in the scatter plot.

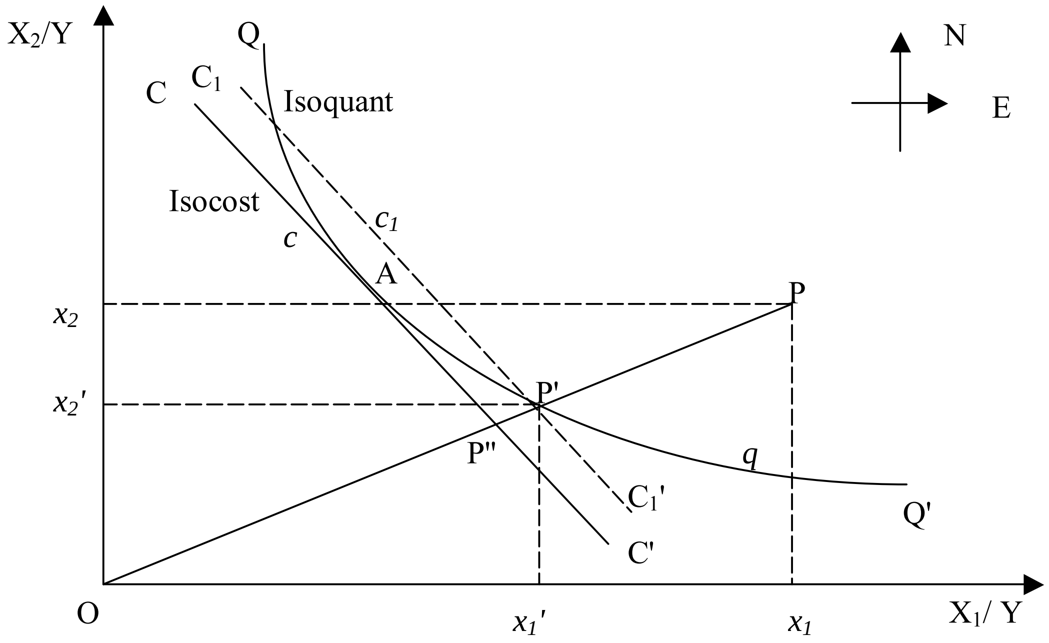

Figure 2. 3 Isoquant: Input-Orientation

Firm P utilizes x_1 and x_2 units of inputs X_1 and X_2 respectively to produce an output of quantity q. For the firm P to perform efficiently, it should use x_1' and x_2' units of inputs respectively to produce the same quantity q of the output Y. In other words, the firm P would have been operating efficiently, if it uses x_1 and x_2 units of the inputs to produce q units of the output Y.

Based on the former discussion, where the inputs are minimized holding the output constant, the technical efficiency of the firm P is given as OP'/OP. This means that the two inputs can be reduced by a proportion equal to OP'/OP. Reducing input X_1 by a proportion OP'/OP from x_1 means to bring it down to x_1' units. A similar proportionate reduction is done for the input X_2 to reduce it from x_2 to x_2'.

In addition to the technical efficiency that is based on the best practices, the cost of the inputs should also be considered to determine the overall performance of the unit under investigation since the costs of an input is different from that of the others. The line CC' is the isocost line representing the various combinations of the two inputs that have the same total cost c. The slope of the isocost line is determined by the ratio of the costs.

The isocost line CC' is tangential to the isoquant QQ' at point A. This firm that is represented by the point A would have the best technical and allocative efficiency. Allocative efficiency portrays the ability of the firm to use the inputs in optimal proportions so that the resource cost is minimized. Firm P' which is also the projection of firm P onto the isoquant QQ' is also as technically efficient as firm A, but is not as allocatively efficient as A. This is because, the cost of production at point P' would be the cost associated with the isocost line C_1C_1', which is c_1. From our initial set up of this example, the cost c_1 is higher than the cost c. The allocative efficiency of the firms P and P' is the ratio OP'/OP.

The total economic efficiency of the firm P is defined as the ratio OP"/OP ((Farrell 1957). This ratio is defined as follows

$$OP''/OP = OP''/OP' \times OP'/OP$$

That is,

Total economic efficiency = Allocative efficiency x Technical efficiency **(2.2)**

These three efficiency measures have a range of (0,1). It was here assumed that the efficient production function was known. This is not true in most of the practical scenarios. The production function is either too complicated to be represented or may not be known at all. Farrell (1957) suggested the use of a non-parametric piece-wise linear convex isoquant such that in either case, no firm lies either to the left or to the bottom of the isoquant. Such a function envelops such that all the all the data points are to the north east of it.

2.4.3 Output Oriented Models

The output oriented models look at the extent to which the outputs produced can be increased without an increase in the inputs and hence is known as the output-increasing measure of technical efficiency. This can be illustrated using Figure 2.4. It is an example firm that produces two outputs with one input. Y_1 and Y_2 are the outputs and X is the Input.

QQ' is the isoquant that represents a constant quantity of input that is used to produce varying proportions of the two outputs. It is concave to the origin and since it determines the best production possibility, all the firms lie to the left and the bottom of QQ'. A is one such firm. Point B is the projection of the firm A onto the isoquant QQ'. Here the distance AB determines the amount of technical inefficiency. Hence the output-oriented technical efficiency measure is given by OA/OB. If the prices of the outputs are also known, then the isorevenue line RR' can be drawn and the allocative efficiency can also be determined as OB/OD. Then the overall efficiency would be the product of the two efficiencies and would be the ratio OA/OD.

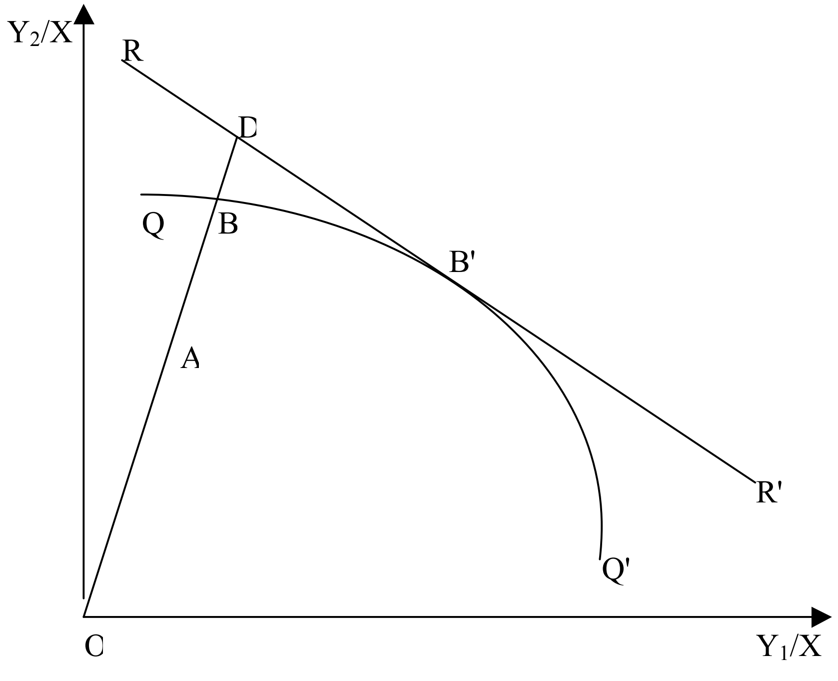

Figure 2. 4 Output-Orientation

Both the efficiency measures described above are based on the constant returns to scale technology. Constant returns to scale implies that an increase in all inputs by a proportion increases the outputs by the same proportion. This is not true with all the production scenarios. It may also not be applicable to the case of intersections. The more general returns to scale types are described below with an example firm (one input (X), one output (Y)).

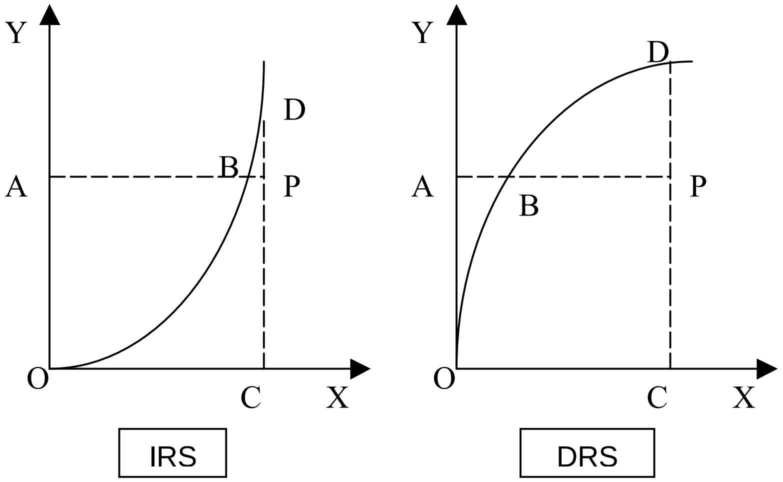

Figure 2.5 Returns to Scale

Increasing returns to scale (IRS) is the scenario where an increase in the input results in an increase in outputs larger than the increase in inputs by proportion. Decreasing returns to scale is when an increase in input by a certain amount results in increase in the outputs lesser than the quantity of inputs increased.

The input reducing and the output increasing measures give the same technical efficiency score under the assumption of constant returns to scale. However, in the case of variable returns to scale, both measures give different efficiency scores. It can also be seen that the increasing returns to scale assumption tends to increase the distances either AB or CD.

DEA is based on the assumption of convexity, which states that for any two points that are feasible, their convex combination is also feasible. This means that for two observed DMUs lying on the frontier one can prove that their convex combination is feasible and also lies on the frontier. Based on this assumption, DEA compares actual firms to virtual firms that are the weighted combinations of actual firms.

2.5 Peers and performance Goals

Peers are the units that are on the frontier or on the best practice frontier. These are used as the reference of comparison for inefficient units. In Figure 2.6, there is set of comparable units {A, B, C, D, E, F, G} that produce an output by using two inputs. A, B and G lie completely to the northeast of the frontier and are inefficient. Firm A is projected onto the frontier by drawing a line that connects the origin with A and it falls on point D, which is an actual firm. Hence, firm D is the peer of firm A with respect to efficiency measurement. In this case, firm A is compared to the actual firm D. However, B' is the projection of firm B onto the frontier. Here, since it falls on the frontier between firms D and E, both D and E are the peers of firm B and firm B is compared to the weighted combination of D and E. The weighted combination of B is assumed to be achievable in reality. This is based upon the characteristic called the disposability of inputs and outputs.

Disposability of inputs is the ability with which an input can be disposed off holding the remaining inputs constant while at the same time the resulting input set still remains part of the production possibility set. Disposability of outputs is the ability with which an output can be disposed off holding the remaining outputs constant while at the same time the resulting output set still remains part of the production possibility set.

The private disposal cost distinguishes the two different types of disposability. Strong disposability is the ability to dispose of an unwanted commodity with no private cost and weak disposability is the ability to dispose of an unwanted commodity at positive private cost.

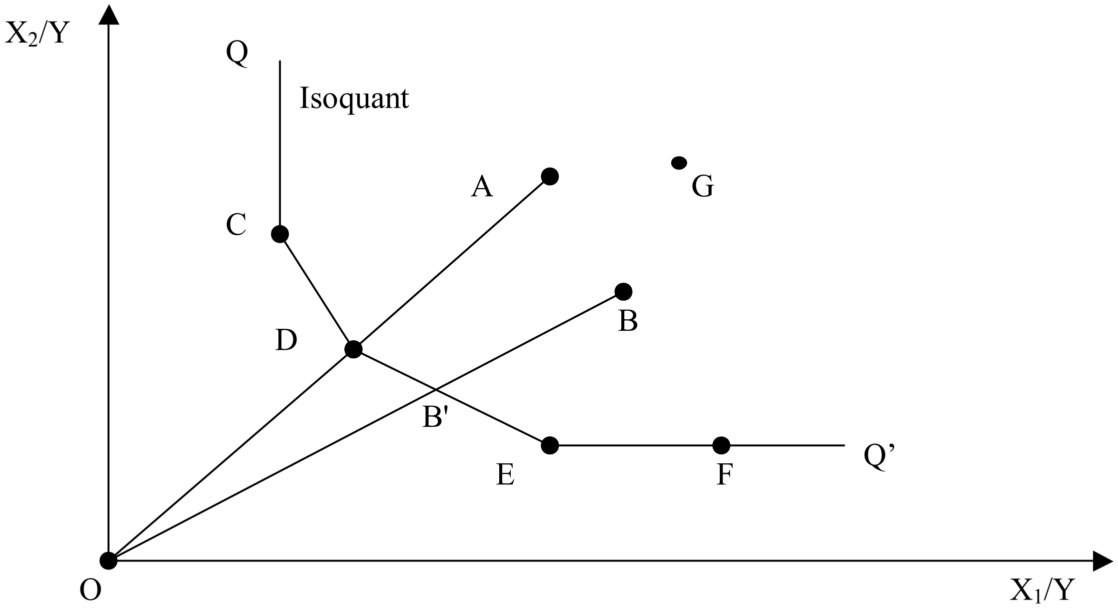

Figure 2.6 Peers and Performance Goals

The amount of input X_1 given by the distance EF is the excess of input X_1 used by firm F. Hence the slack associated with input X_1 for firm F should also be taken into account while determining its efficiency score. A similar discussion pertains for the outputs, where the slacks with respect to the outputs would be termed as a shortfall in production.

The goal of an inefficient unit is to perform like the best of its peers. That sets the performance goals for that unit. It may well be explained by saying that b will want to produce the same amount of output that it is producing currently by using just as much inputs (both X_1 and X_2) as the virtual unit B' is using.

2.6 Relative Efficiency

DEA uses a the following definition of relative efficiency as it's principle. The measurement of relative efficiency when the subject unit involves multiple inputs and outputs was addressed by assigning weights to the variables so that the overall relative efficiency score is actually a ratio of the weighted sum of the outputs to the weighted sum of the inputs by Farrell (1957).

$$\text{Efficiency} = \frac{\text{Weighted sum of outputs}}{\text{Weighted sum of inputs}} \qquad \textbf{(2.3)}$$

The use of this concept in DEA based models is described in detail in Chapter3. The weights here could be compared to the costs of corresponding inputs and outputs and by having the same set of costs across all the units under consideration; the individual units are given any freedom to choose their own prices that best suits them to maximize their efficiency. This is overcome by DEA. It is explained in Chapter 3 how DEA overcomes this problem of evaluating under predefined set of criteria.

2.7 DEA and Relative Efficiency

The definition of relative efficiency forms the basis of data envelopment analysis. The relative efficiency is typically represented in the following mathematical form,

$$\eta_j = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \quad j = 1,2,3, \ldots n$$

where, **(2.4)**

η_j – *relative efficiency of unit* j

u_r – *weight on output* r

v_i – *weight on input* i

y_{rj} – *quantity of output* r *for unit* j

x_{ij} – *quantity of input* i *for unit* j

n number of firms with m number of inputs and s number of outputs are considered here. x_{ij} represents the inputs and y_{rj} represents the outputs of firm j.

There are drawbacks in trying to compute the relative efficiency of units by assigning weights based on the determined costs for each input and output. The drawbacks are that it is difficult to determine precise costs and it is also inappropriate to attach the same costs for inputs and outputs across all units as the actual cost of these may be different for units. Charnes, Cooper and Rhodes (1978) introduced a model that would allow the different units to pick their best weights for the inputs and outputs to obtain the best possible relative efficiency score for itself. The details of this model are given below. Charnes, Cooper and Rhodes also introduced the term "Decision Making Units" (DMU) for the entities that are compared.

2.7.1 The CCR Model

This is a fractional programming model developed by Charnes, Cooper and Rhodes (1978) that determines the efficiency scores of the DMUs in a data set of comparable units. This model determines the best set of weights for each DMU when the problem is solved for each DMU under consideration.

$$\begin{aligned} \max h_0 &= \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}} && \mathit{for\ DMU}_0 \\ \mathit{subject\ to} & \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \le 1 && j = 1,2,3,\ldots n \\ v_i & \ge 0 && i = 1,2,3,\ldots m \\ u_r & \ge 0 && r = 1,2,3,\ldots s \end{aligned} \qquad \textbf{(2.5)}$$

Here the x, y, h, u, v are the same as in equation 2.5. This is converted to the following form to make it a linear program. This is done for the reason that linear programs are easy to solve. ε is the weight restriction introduced here as none of the inputs or the outputs are totally ignored by getting a weight of zero assigned to them.

The objective function maximizes the efficiency of the DMU using the weights u_r and v_i for the outputs and the inputs respectively. The model determines the weights such that the efficiency score of the DMU under consideration is maximum and when the same set of weights are applied to the other DMUs in the sample their efficiency score cannot exceed one. The mathematical formulation is as follows.

$$
\begin{aligned}
&\max h_0 = \sum_{r=1}^{s} u_r y_{rj_0} && \quad \textit{for } DMU_0 \\
&\textit{subject to } \sum_{i=1}^{m} v_i x_{ij_0} = 1 && \\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0 && \quad j = 1,2,3,\ldots n \\
&v_i \ge \varepsilon && \quad i = 1,2,3,\ldots m \\
&u_r \ge \varepsilon && \quad r = 1,2,3,\ldots s
\end{aligned}
\qquad \textbf{(2.6)}
$$

Since the above form has a lot of constraints, it is hard to solve. The other form of the same model commonly known as the dual form is as follows. There is a variable introduced for every constraint. These new variables are λ_j, Z_0, s_i^- and s_r^+. These variables represent slacks in the constraints [4].

Based on the introduction of new variables as above, the envelopment or dual form of the CCR model is as follows.

$$\begin{array}{llll}
\min & z_0 - \varepsilon\sum_{r=1}^{s} s_r^+ - \varepsilon\sum_{i=1}^{m} s_i^- & \textit{for } DMU_0 & \\
\textit{subject to} & x_{ij_0} z_0 = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- & i = 1,2,3,\ldots m & \\
 & \sum_{j=1}^{n} y_{rj}\lambda_j = y_{rj_0} + s_r^+ & r = 1,2,3,\ldots s & \textbf{(2.7)} \\
 & \lambda_j \geq 0 & j = 1,2,3,\ldots n & \\
 & s_r^+ \geq 0 & r = 1,2,3,\ldots s & \\
 & s_i^- \geq 0 & i = 1,2,3,\ldots m & \\
 & z_0 \quad \textit{unconstrained} & &
\end{array}$$

2.7.2 The BCC Model

The CCR model assumes constant returns to scale. Banker, Charnes and Cooper (1984) proposed a model that modified the CCR model by adding a constraint to account for the variable returns to scale as explained in Section 2.4.3.

The BCC model would be the same as the CCR model as shown above with an added constraint as follows.

$$e\lambda = \sum_{j=1}^{n} \lambda_j = 1 \qquad \textbf{(2.8)}$$

These two models described above do not deal with undesirable outputs. It has been assumed that all of the outputs are desirable, as the model has been trying to increase the outputs regardless of the nature of outputs. In any production process, production of desirable products is accompanied by the production of few undesirable outputs. In the case of four way signalized intersections, undesirable delay to the number of vehicles that are getting past the intersection is produced during the process getting the vehicle past the intersection.

To capture this concept, the following two models are found to be useful.

2.7.3 Färe's Index model

Färe (1986) was the first to apply output oriented DEA analysis to steam electric plants. In this paper the authors defined radial efficiency measures for equi-proportional increase of all the outputs, both desirable and undesirable. The technology set was characterized by strong and weak disposability of the undesirable outputs in order to check for production congestion a phenomenon common in production bases industries.

Färe (2000) provides a formal index number of environmental performance that can be computed using DEA techniques. The procedure is to determine an output distance function based on the degree to which the desirable outputs could be expanded for each DMU. This is represented by the quantity index of desirable outputs. . For the undesirable outputs, the degree of reduction possible is determined for each DMU that is represented by the quantity index of undesirable outputs. The overall environmental performance index is given by the ratio of the quantity index of the desirable outputs to the quantity index of the undesirable outputs.

Let us define the following notation for the vector of inputs (x), the desirable outputs (p), the undesirable outputs (q) and the outputs (y: union of p and q) respectively.

$$\begin{aligned} &x=(x_1,x_2,\dots x_M)\in\Re_+^M \\ &p=(p_1,p_2,\dots p_N)\in\Re_+^N \\ &q=(q_1,q_2,\dots q_J)\in\Re R_+^R \\ &y=(p,q)\in\Re_+^{N+R} \end{aligned} \qquad \textbf{(2.9)}$$

The technology has all feasible vectors (x, y)

$$T=\{(x,y): x\ can\ produce\ y\ where\ y=(p,q)\} \qquad \textbf{(2.10)}$$

The assumptions for this model are as follows.

1. Weak disposability of outputs:

$$If\ (x,y)\in T\ and\ 0\le\theta\le 1\ then\ (x,\theta y)\in T\ where\ y=(p,q) \quad \textbf{(2.11)}$$

The weak disposability assumption is that both the desirable and the undesirable outputs can be disposed proportionally. It also implies that it is not possible to reduce only the undesirable outputs (total delay (VD), number of stops (NS)) holding the inputs (total number of lanes (N), Phasing Coefficient (P) and Timing Coefficients (TC)) and the desirable output (total number of vehicles getting past the intersection (V)) constant. This is verifiably true based on equation 3.9 to 3.13 presented in Chapter 3.

2. Null Jointness:

This assumption means that it is technically impossible to produce only desirable outputs (V) without producing any of undesirable outputs (VD). It also means that the only way to totally eliminate the production of the undesirable outputs is to stop the production of the desirable outputs. This holds well for four way signalized intersection, as it is not possible to get vehicles past intersection with out producing any delay at all. The only way delays (VD) totally is not to have an intersection as the vehicles will get past this spot at the free speed. Presence of an intersection always results in an increase in the time for vehicles to get through it.

$$If\ (x,y)\in T\ where\ y=(p,q)\ and\ q=0\ then\ p=0 \quad \textbf{(2.12)}$$

3. *T* is a closed set.

This assumption implies that the production possibility set also includes all the points on the frontier. Any point on the frontier that is a vertex represents a real DMU. Other points on the frontier are virtual composite DMUs used for comparison after the projection onto the frontier.

This assumption holds good for intersections, as it is always possible in a region to find other isolated intersections that may exist as the virtual composite DMU.

4. Inputs are freely or strongly disposable.

This means that, if an amount y can be produced from x, then y can be produced from any $x' \geq x$. In words, it means that the amount of input can be increased without an increase in the amount of outputs. This holds good for this analogy, as it is possible to include more lanes, use operationally better phasing system and use higher cycle times with out an increase in the desirable and undesirables outputs.

5. The desirable outputs are freely or strongly disposable.

This means that if a given quantity of desirable output p can be produced from x, and for any amount $p' \leq p$, p' can also be produced from x. This apparently holds good as a lesser number of vehicles could be moved with the same inputs.

Then the output distance function for the desirable output (total number of vehicles getting through the intersection) is defined as follows. This distance function represents how far are the desired outputs from the peer best practice desired output.

$$D_p(x, p, q) = \inf\{\theta : (x, p/\theta, q) \in T\} \qquad \textbf{(2.13)}$$

The function "inf" here represents the minimizing.

Let x^0 and q^0 be the input and the undesirable output vectors and let p^k and p^l be the desirable output vectors that are being compared. Then the quantity index of good outputs is given by

$$Q_p(x^0, q^0, p^k, p^l) = D_p(x^0, p^k, q^0) / D_p(x^0, p^l, q^0) \qquad \textbf{(2.14)}$$

This index should satisfy the following properties

1. Homogeneity

$$Q_p(x^0, q^0, \lambda p^k, p^l) = \lambda Q_p(x^0, q^0, p^k, p^l) \tag{2.15}$$

The quantity index is based on the distance function. The distant function is a radial measure. The property of homogeneity represents that the distance of the DMU from the frontier changes proportional to the increase or decrease in the desired output.

2. Time reversal:

$$Q_p(x^0, q^0, p^k, p^l).Q_p(x^0, q^0, p^l, p^k) = 1 \tag{2.16}$$

3. Transitivity:

$$Q_p(x^0, q^0, p^k, p^l).Q_p(x^0, q^0, p^l, p^s) = Q_p(x^0, q^0, p^l, p^s) \tag{2.17}$$

4. Dimensionality:

$$Q_p(x^0, q^0, \lambda p^k, \lambda p^l) = Q_p(x^0, q^0, p^k, p^l) \tag{2.18}$$

This can be explained with the help of homogeneity.
From equation 2.15

$$Q_p(x^0,\ q^0,\ \lambda p^k,\ \lambda p^l) \ = \ \lambda Q_p(x^0,\ q^0,\ p^k,\ \lambda p^l) \tag{2.19}$$

Equation 2.18 and 2.19 imply that

$$Q_p(x^0,\ q^0,\ p^k,\ \lambda p^l) \ = \ (1\ /\ \lambda) Q_p(x^0,\ q^0,\ p^k,\ p^l)$$

This explains that the radial measure has proportionality with various dimensions of the solution space where each dimension represents a desirable output.

A distance function is also determined for the undesirable outputs similar to the desirable outputs. It is given by:

$$D_q(x,\ p,\ q) \ = \ \sup\{\lambda \ : \ (x,\ p,\ q\ /\ \lambda) \ \in \ T\} \qquad \textbf{(2.20)}$$

The function "sup" here represents maximization.

Then the undesirable output quantity index is given by:

$$Q_q(x^0,\ y^0,\ b^k,\ b^l) \ = \ D_q(x^0,\ y^0,\ b^k)\ /\ D_q(x^0,\ y^0,\ b^l) \qquad \textbf{(2.21)}$$

These quantity indexes also possess homogeneity, time reversal, transitivity and dimensionality properties. The environmental performance index for the steam electric plants was defined as:

$$E^{k,l}(x^0, p^0, q^0, p^k, p^l, q^k, q^l) = \frac{Q_p(x^0, q^0, p^k, p^l)}{Q_q(x^0, p^0, q^k, q^l)} \quad \textbf{(2.22)}$$

The linear programs used to compute the values of the distance functions are as follows.

Desirable outputs:

$$\begin{aligned}
&\max \quad \theta((D_p(x^0,\ p^{k'},\ q^0))^{-1}) \\
&s.t. \sum_{k=1}^{K} \ z_k p_n^k \ \geq \ \theta p_n^{k'},\ n \ = \ 1,\ldots N \\
&\sum_{k=1}^{K} \ z_k q_r^k \ = \ q_r^0,\ r \ = \ 1,\ldots R \qquad\qquad \textbf{(2.23)} \\
&\sum_{k=1}^{K} \ z_k x_m^k \ \leq \ x_m^0,\ m \ = \ 1,\ldots M \\
&z_k \ \geq \ 0,\ k \ = \ 1,\ldots K
\end{aligned}$$

Similarly, the following linear program calculates the distance function for undesirable outputs:

$$
\begin{aligned}
&\min \quad \lambda((D_q(x^0,\ p^0,\ q^{k'}))^{-1}) \\
&s.t. \sum_{k=1}^{K} z_k p_n^k \ \geq \ p_n^0,\ n \ = \ 1,\ldots N \\
&\sum_{k=1}^{K} z_k q_r^k \ = \ \lambda q_r^{k'},\ r \ = \ 1,\ldots R \\
&\sum_{k=1}^{K} z_k x_m^k \ \leq \ x_m^0,\ m \ = \ 1,\ldots M \\
&z_k \ \geq \ 0,\ k \ = \ 1,\ldots K
\end{aligned} \qquad \textbf{(2.24)}
$$

Quantity index of the desired (undesired) output is the ratio of the distance function of the desired (undesired) outputs that is calculated using the linear programs above to the distance function of desired (undesired) outputs for reference DMU that has been determined. Using the quantity indices for desired and undesired outputs, the environmental index is calculated. Here the model also assumes that the improvements in the desired outputs and the undesired outputs are linear and they are independent of each other.

As examined here, Färe's index model may be used to model four way signalized intersections. This model uses radial measurement of distances for the calculation of indices. The next model described below presents a different measurement of distances.

2.7.4 Hyperbolic Efficiency Measure

This model was introduced by Färe in 1989 with a different approach than the previous index approach. This model incorporates both the desirable outputs and the undesirable outputs in the model. They allowed the desirable outputs to increase by some proportion and at the same time allowed the undesirable outputs to decrease by the same proportion.

Zofio and Prieto (2001) assessed the environmental performance of a set of producers by grading their ability to produce "the largest equi-proportional increase in the desirable output and decrease in the undesirable output."

The following diagram explains the difference in hyperbolic efficiency measure and the radial efficiency measure. Here the strong disposal reference technology for the inputs and the outputs is represented by the output set: which is represented by OFBCE in Figures 2.7.

$$R^S(x):[(p,q): p \le Pz, q \le Qz, x \ge Xz; z \in \Re_+^K] \qquad \textbf{(2.25)}$$

In the above expression, the superscript in $R^S(x)$, represents strong disposability. $\Re^K_+$ is the standard notation to represent the positive side of a K-dimensional space. $R^W(x)$ represents weak disposability of x.

$$R^W(x):[(p,q): p \le Pz, q = Qz, x \ge Xz; z \in \Re_+^K] \qquad \textbf{(2.26)}$$

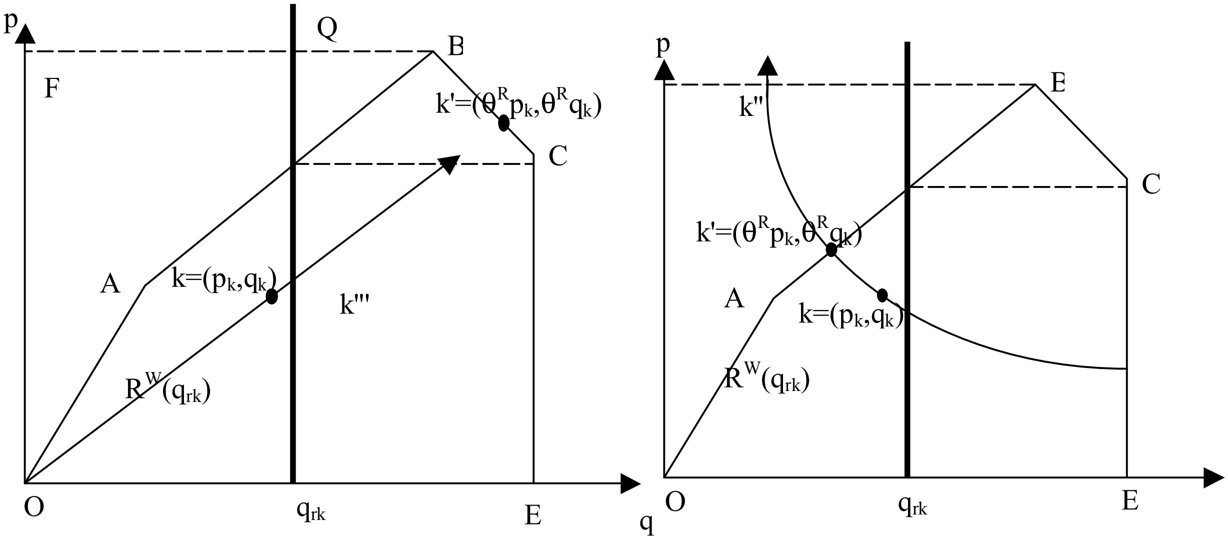

Figure 2.7 Radial Vs. Hyperbolic Measure

k =(p_k, q_k) represents kth DMU. A, B, C and E are the other DMUs. Considering the section OAB of the frontier in the figure, it can be seen that any reduction in the undesirable outputs results in a reduction of the desirable outputs. If the reduction in the desirable outputs has to be avoided, then the desirable outputs have to be held constant. This results in an increase in the usage of the inputs. In either case there is a cost associated with the disposal of the undesirable outputs and it is not free, hence the weak disposability of undesired outputs.

Assuming the same production possibility set, the functional representations of the reference technologies for radial measure (equation 2.27) and hyperbolic measures (equation 2.28) are given as follows.

$$D^R(p,q) = \{\theta^R : y\theta^R \in R(x)\} \qquad \textbf{(2.27)}$$

$$D^H(p,q) = \{\theta^H : (p\theta^H, q/\theta^H) \in R(x)\} \qquad \textbf{(2.28)}$$

These distance functions are regarded as performance measures and are evaluated to determine the scores of the firms. The final efficiency score is given as the reciprocal of the distance function. If the expansion of either the radial or the hyperbolic distance functions is infeasible, then the respective distance function has a value of one, i.e. $\theta^R = \theta^H = 1$.

Such firms are characterized as efficient. This happens for the DMUs that are on the frontier. On the other hand, if the distance functions are expandable, then $\theta > 1$ and hence the production process is considered inefficient. The radial and hyperbolic measures of distance functions can be defined as follows.

$$E_{1k}^R(p_k, q_k, x_k) = \max[\theta^R : (\theta^R p_k, \theta^R q_k) \in R^S(x_k)] \qquad \textbf{(2.29)}$$
$$E_{1k}^H(p_k, q_k, x_k) = \max[\theta^H : (\theta^H p_k, q_k/\theta^H) \in R^S(x_k)] \qquad \textbf{(2.30)}$$

These measures (2.29 (radial) and 2.30 (hyperbolic)) are calculated using the following two formulations equations 2.31 (radial), 2.32 (hyperbolic) and 2.33 (hyperbolic).

$$\begin{aligned}
&E_1^S(p_k, q_k, x_k) = \max[\theta : (\theta p_k, \theta q_k) \in R^S(x_k)] \\
&s.t. \\
&\theta p_k \leq Pz \\
&\theta q_k \leq Qz \\
&Xz \leq x_k \\
&z \in \Re_+^K
\end{aligned} \qquad \textbf{(2.31)}$$

Brannlund (1995) used the above formulation for Swedish pulp and paper industry with environmental standards. The above measure increases both the desires and undesired inputs by similar proportions. This is not very appropriate when environmental concerns are abounded. The hyperbolic measure based formulation as shown below works better in those situations. Formulation in 2.31 assumes weak disposability of undesired outputs. A production process is said to exhibit strong disposability of undesirable outputs if the undesirable output can be freely disposed without any change in the desirable outputs or in the inputs. The weak disposability of undesirable outputs implies that a reduction in the undesirable output forces a proportional reduction in the desirable output as well. This leads to congestion in production.

Since the hyperbolic measure tries to reduce the undesirable output while increasing the desirable output, the existence of congestion can be determined by evaluating the firm successively under strong and weak disposability assumptions. If the efficiency scores obtained from both the assumptions are the same, then the firm's production process is not affected by congestion. Hence the undesirable outputs can be reduced without any reduction in the desirable outputs. On the other hand, if the scores are different, then congestion is said to exist and weak disposability is binding.

The following linear program assumes strong disposability reference technology for undesirable outputs.

$$
\begin{aligned}
&E_1^S(p_k, q_k, x_k) = \max[\theta : (\theta p_k, \theta^{-1} q_k) \in R^S(x_k)] \\
&s.t. \\
&\theta p_k \le Pz \\
&q_k / \theta \le Qz \\
&Xz \le x_k \\
&z \in \Re_+^K
\end{aligned}
\qquad \textbf{(2.32)}
$$

In the above linear program, the constraints for the desirable and the undesirable outputs have a '≤' which accounts for the strong disposability of both the outputs.

$$
\begin{aligned}
&E_1^W(p_k, q_k, x_k) = \max[\theta : (\theta p_k, \theta^{-1} q_k) \in R^W(x_k)] \\
&s.t. \\
&\theta p_k \le Pz \\
&q_k / \theta = Qz \\
&Xz \le x_k \\
&z \in \Re_+^K
\end{aligned}
\qquad \textbf{(2.33)}
$$

The above linear program (2.33), uses '=' in the undesirable output constraint to account for the weak disposability of these undesirable outputs while still holding the desirable outputs as strongly disposable. The ratio E_{1k}^S / E_{1k}^W is defined to check for production congestion. If the ratio equals one, then the production does not present weak disposability of undesirable outputs. If the ratio is greater than one, then weak disposability congests the production process.

Since the fare's index model based on the radial measure and the hyperbolic measure based model by Zofio and Prieto (2001) incorporate the undesirable output into the formulation. These are the two models that will be looked at closely in the later chapters.

Chapter 3. Research Methodology

This section explains the selection of an appropriate DEA model, the definition of various parameters and how intersections were modeled for comparison.

The objective of this modeling effort is to rank a set of isolated independent signalized four way intersections based on the identified inputs and outputs. To do this, at first the relative efficiencies of all the intersections in the set are computed. And then considering the cost of the identified improvements required, the ranks for the intersections are determined. Here there is an analogy drawn between an intersection and a production unit.

Figure 3. 1 The Production Process

Figure 3. 2 The Process at Intersections

The measurement of efficiency of any production unit is based on the production theory. Production theory views a firm or production unit as a system where inputs are resources that are utilized and transformed into desirable outputs. This transformation process is depicted in figure 3.1.

3.1 The Analogy

Production theory is based on the following six axioms.

1. Free production is not feasible, i.e., one cannot have positive outputs from production without using one or more of the inputs.
2. Infinite production is not feasible, i.e., finite inputs cannot produce infinite outputs.
3. Proportional increases in inputs do not decrease outputs (“weak disposability of inputs”).
4. Proportional decreases in outputs remain producible with no change in inputs (“weak disposability of outputs”) or another way of stating the same assumption is that a proportional increase in outputs cannot be obtained if inputs are reduced.
5. The correspondence between inputs and outputs is closed
6. The isoquant is convex to the origin; in a two dimensional input space this indicates that if two input bundles can each produce one unit of output, then so can the weighted average of them

It is essential to verify whether any chosen decision making unit (DMU) satisfies these six axioms before we apply any math programming formulations to compute technical efficiency. The compliance of intersection as a production unit, to the production axioms is verified by tests. The compliance of intersections to these tests is discussed later in this Chapter.

We can consider an intersection as a production unit that consumes the below defined three inputs quantifying various factors, producing the desired output, total number of vehicles that get past the intersection and undesirable outputs “average delay per vehicle” and “average number of stops per vehicle”. These following three inputs were identified as the most important factors for performance for the evaluation of four way signalized intersections on the basis of the preliminary assumption that is explained in Section 2.1. Other parameters that will represent the influence of the non-compliance of any of these assumptions may be included as inputs for the intersections in the case of non-compliance.

3.2 Modeling Process

A critical factor for any successful DEA model is identifying the inputs and outputs correct. This is an involving process for the modeler. This subsection explains this process.

Inputs were generally classified as follows.

- Geometric Characteristics
- Travel Characteristics
- Control/Strategy Characteristics
- Phasing system
- Timing system

Comprehensive lists of factors were under each category as follows. This was necessary and helpful in identifying the factors that should be incorporated in the model.

Geometric Characteristics included the following,

- Number of lanes for through movement
- Number of lanes for Left movement
- Number of lanes for Right movement
- Characteristic Lane width
- Characteristic grade (Slope)
- Presence of street parking (yes/No)---(could be one variable for the whole intersection)
- Presence of Pedestrian Crossing
- Presences of push buttons for pedestrian

The Travel Characteristics are listed as below

- The distance of the nearest Intersection from this Intersection of concern (ft.)—(Characteristic of all approaches)
- Volume or Arrival Rate for through Movement
- Volume or Arrival Rate for left Movement
- Volume or Arrival Rate for Right Movement
- Arrival pattern of the vehicles at the intersection.

The first and the last factors were left out of the modeling process later as the modeling was for isolated intersections. Isolated intersections are intersections that are not influenced by the performance of the neighboring intersections in a significant way. This method is envisioned to help the planners for region wide selection of priority intersections to which immediate attention is required. As this was defined as the purpose of the tool, it was decided to model isolated intersections, as those are what planners will be dealing with on a region wide investigation. The other factors were included in the modeling.

The comprehensive list of Control/Strategy factors are as follows,

The factors related to phasing system are

- Number of phases
- Comprehensive phasing coefficient (0<= x <=1)
    - Presence of conflicts in the existing phasing system
    - Summation of severity of conflicts for each conflict
- The comprehensive phasing coefficient included two coefficients.

Coefficient 1

- Presence of Protected left turn (y)(yes [0]/no[1])
- Percentage of left turns (x)
- Coeff1=1-(x*y)

Coefficient 2

- Presence of Conflicts in the existing phasing system
- Coefficient 2 was a representation of severity of conflicts
- Coefficient 2= Sum of (1-{(v1*v2)/(c1*c2))

Timing System

The most influential factor from the timing standpoint was the appropriateness of the present green time.

•Timing coefficient = Sum of all (1-(g/c-v/V)) for each movement.
•Cycle length

The timing coefficient defined in the subsection 3.4.5 was found to be more appropriate as it was a representation of both the cycle length and the appropriateness of the timing strategy.

The identified outputs are as follows

- Number of stops (undesirable output)
- Total Delay time (undesirable output)
- Number of accidents / 1000 entering vehicles (undesirable output)
- Number of vehicles got through (desirable output)
- Number of pedestrians got through (desirable output)

The number of accidents was left out, as that may be included when the purpose is to rank the intersections for impending safety related improvements. It is not the state of the practice yet to collect data on the number of pedestrians that cross the streets. If the data collection is made available and if the intersections are predominantly the downtown ones where there is a very significant pedestrian presence, this may be included. But for the purpose as defined in Chapter 1, these factors were excluded from the modeling.

3.3 Definition of Terms Used in Indices

The basic terminology of traffic signals is described and the various types of signal operation and their impact on capacity are outlined briefly to facilitate the understanding of the indices described later. The following terms are those commonly used to describe traffic signal operation are presented here from Highway Capacity Manual (2).

Cycle - any complete sequence of signal indications.

Cycle Length - the total time for the signal to complete one cycle, stated in seconds and given the symbol C.

Interval - a period of time during which all signal indications remains constant.

Phase - the part of a cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals.

Green Time - the time within a given phase during which the green indication is shown, stated in seconds and given the symbol G.

Lost Time – time during which the intersection is not effectively used by any movement, which occurs during the change- and clearance intervals (when the intersection is cleared) and at the beginning of each phase as the first few vehicles in a standing queue experience start –up delays, given the Symbol L.

Effective Green Time - the time that is effectively available to a movement, generally taken to be the green time plus the change and clearance interval minus the lost time for the designated movement, stated in seconds and given the symbol g.

Effective green ratio – the ratio of effective green time to the cycle length, given the symbol, g_i/C.

Effective red time – the time during which the given movement or set of movements is effectively not permitted to occur, the cycle length minus the effective green time, stated in seconds and given the symbol r_i.

Traffic Engineering books describe three types of traffic signal controllers as listed below.

Pretimed Controllers- a preset sequence of phases is displayed in repetitive order. Each phase has a fixed green time and a change- and clearance interval that are repeated in each cycle to produce a constant cycle length.

Fully Actuated Controllers – the timing of all of the approaches to an intersection is influenced by vehicle detectors. Each phase is subject to a minimum and a maximum green time, and some phase may be skipped if no demand is detected. The cycle length for fully actuated control will vary from cycle to cycle.

Semi Actuated Control – Some approached (typically on the minor street) have detectors, and some do not. The earliest form of semi-actuated control was designed to confine the green indication to the major street in the absence of demand on the minor streets. Once actuated, the minor street green is displayed for a period just long enough to accommodate the traffic demand on the minor street.

The indices that have been defined below can be used for all of the control strategies with an additional index for the control strategy as an input. This is an input because this is an extraneous infrastructure related practice that is provided to the intersections outside of the production process. One possible way for this defining this index for the control strategy is to have [0,0.5,1] .the three values this index can take. 0, 0.5 and 1 should be assigned to pretimed, semi actuated and fully actuated respectively.

As a preliminary analysis of the potential use of DEA for the objectives of this research, only the pretimed control strategy has been modeled here. The following subsections list all these identified inputs and outputs that were included in the DEA Model for the evaluation of signalized intersections.

3.4 Inputs

The inputs are identified as the resources that are being consumed by the production unit in a traditional sense of a production unit. In the case of an intersection, the inputs are of three types.

1. Geometrical characteristics
   This is calculated as the weighted average of number of lanes for various movements in different approaches. It is represented as an independent input.
2. Phasing characteristics
   (a) Number of phases:
   This is incorporated into the Timing Coefficient (TC) detailed below.
   (b) Phasing coefficient:
   This is considered as a separate input into the model.
3. Timing characteristics
   This is used in the model as an independent input.

3.4.1 Geometrical Characteristics: Total Number of lanes (N)

Geometrical characteristics are the physical characteristics that define an intersection. This would typically include the details such as the grades of the approaches. The alignment of one approach to each other, number of lanes of each approach, presence of left turn bay, lane alignments, lane width and presence of pedestrian crossing. For the purpose of this study, it was determined from the literature that number of lanes would be the most significant factor in terms of physical infrastructure of intersections that would be of interest to the planning authorities since lanes are such scare resources. Additional lanes may cost in the tunes of millions. It is also important that the lanes are in place where the maximum demand is. This led to consider the weighted average of these lanes for each movement while the weights are the demand volume for each movement.

This input variable is defined as the weighted sum of all the lanes available.

a. N_i where i= 1,2,3 or 4 is the sum of

i. N_{iL} (The number of left turning lanes i^{th} way),
ii. N_{iT}, (The number of through lanes i^{th} way) and
iii. N_{iR} (The number of right turning lanes i^{th} way).

b. This input could be represented as follows

$$N = \frac{1}{V} \sum_{i=1}^{i=4} V_i N_i \tag{3.1}$$

$V_i N_i = V_{iL} N_{iL} + V_{iT} N_{iT} + V_{iR} N_{iR}$ When NiL and NiR are not “0”. **(3.2)**
$V_i N_i = (V_{iL} + V_{iT}) N_{iT} + V_{iR} N_{iR}$ When NiL=0 and NiR is not “0”
$V_i N_i = V_{iL} N_{iL} + (V_{iR} + V_{iT}) N_{iT}$ When NiR=0 and NiL is not “0”
$V_i N_i = (V_{iL} + V_{iT} + V_{iR}) N_{iT}$ When NiL=0 and NiR = 0.

$$V_i = V_{iL} + V_{iR} + V_{iT}$$

$$V = \sum_{i=1}^{i=4} V_i$$

3.4.2 Phasing Characteristic: Introduction

It has been established for a fact that an appropriate phasing system is a key for the successful operation of any signalized intersection. Since there is lot of subjectivity in the selection of the phasing system, it was believed that it was necessary to include all the characteristics of the phasing system in the model. This created a necessity to find a way to represent the phasing system in a mathematical form. The phasing coefficients were developed for such representation.

Number of phases has a significant influence on the performance of the intersections. As each phase has a lost time in the form of delay in the driver realization and the time for the vehicle to accelerate, the number of phases influences the performance of the intersection. Having higher number of phases in a phasing system for the intersection will reduce the over all delay an intersection as well as the average number of stops per vehicle. Having relatively higher number of lanes for the approaches with higher demand improves the operational performance of an intersection.

The number of phases (P) varies between 2 and 4 including the bounds in the data that was created for the demonstration purposes of DEA Model. The intersections in general can have up to 8 phases depending on the complication of it.

The number of phases was combined with the timing characteristics as described in Section 3.3.6 and 3.3.5.

The following is the coefficient to represent the appropriateness of the phasing system that is present in the system for the turning and through volumes. This coefficient value is calculated based on the following parameters.

1. Presence of conflicts including the conflicts by the permitted left turn phasing systems.

2. The severity of each of these conflicts in each of these phases

3.4.3 Phasing Characteristic: Phasing Coefficient (PC)

Presence of conflicts in the existing phasing system is represented by this coefficient. For each phase, the number of conflicts and for each of those conflicts in a phase the severity coefficient is calculated. The diverging conflicts are not as severe as the converging conflicts and also the number of diverging conflicts for comparable four way intersections as defined in Chapter 2 are the same in almost all the cases. So, the converging conflicts are alone considered. ncp_i is the number of converging conflicts in the i^{th} Phase (Here i=P (the number of phases), $4 \leq i \leq 10$). C_{iM}, C_{jM} are the capacities based on the number of lanes available for the two movements in conflict.

V_{kiM}, V_{kjM} are the volumes of the two movements in conflict for the conflict number k. M here can be L, T or R. The severity of a conflict is calculated as follows

$$PC=\sum_{k=1}^{k\text{-}ncp_i}\frac{V_{kiM}\times V_{kjM}}{C_{kiM}\times C_{kjM}} \qquad \textbf{(3.3)}$$

The operational performance (number of vehicles getting past this intersection per hour) of an intersection is higher for higher values of these conflicts as the control strategy relies on the driver judgment to use the gaps available in the conflicting movement. The coefficient follows the generic perception of higher inputs leading to higher output (number of vehicles getting past this intersection per hour).

The calculation of this coefficient is illustrated here with an example.

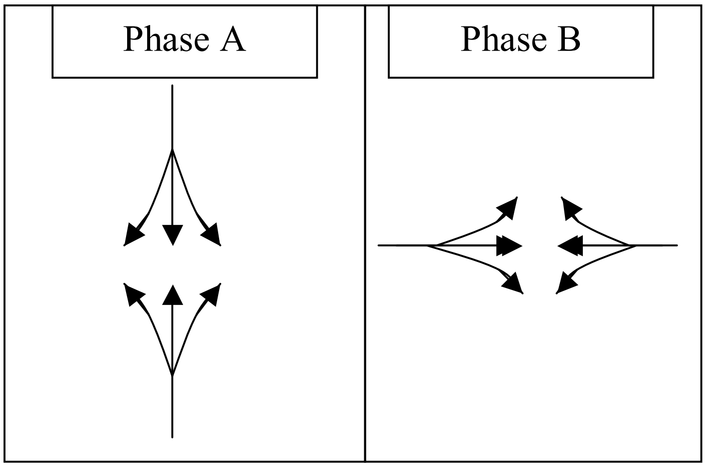

Figure 3.3 Example Phasing Plan

The phasing Coefficient is calculated as follows,

No of conflicts=4

$$PC = \frac{V_{11L}\times V_{13T}}{C_{11L}\times C_{13T}}+\frac{V_{21L}\times V_{23T}}{C_{21L}\times C_{23T}}+\frac{V_{33L}\times V_{34T}}{C_{33L}\times C_{34T}}+\frac{V_{44L}\times V_{43T}}{C_{44L}\times C_{43T}}$$

$$=\frac{V_{1L}\times V_{3T}}{C_{1L}\times C_{3T}}+\frac{V_{3L}\times V_{1T}}{C_{3L}\times C_{1T}}+\frac{V_{3L}\times V_{4T}}{C_{3L}\times C_{4T}}+\frac{V_{4L}\times V_{3T}}{C_{4L}\times C_{3T}}$$

$$=\frac{V_{1L}\times V_{3T}}{1200\times 2400}+\frac{V_{3L}\times V_{1T}}{1200\times 2400}+\frac{V_{3L}\times V_{4T}}{1200\times 2400}+\frac{V_{4L}\times V_{3T}}{1200\times 2400}$$

The calculations of the phasing coefficient for other phasing plans are provided in Appendix A.

3.4.4 Timing Characteristic: Introduction

Once the phase is determined, based on the traffic volumes for each approaches, time allocation is done. This is very critical to the optimal operation of the intersection. Many a times, the timings are not updated in three or four years during which time the changes in the traffic volume might even have doubled in one of the approaches while the other approach might have just one third of it's volume while the signal timing was done. It should also be noted that the number of phases influences the performance in a significant way. Timing and the number of phases can be combined in the following way to produce one index.

3.4.5 Timing Characteristic: Timing Coefficient (TC)

The following coefficient represents the number of phases, appropriateness of the effective green times provided for each movement at an intersection and also the cycle length of timing characteristics. The cycle length and the effective green time for each movement influences the total delay at the intersections in a big way. Delay is the time that a vehicle has to wait to get its turn to get past the intersection from the time at which the vehicle arrived at the intersection. If the cycle length is too short then, the number of stops (every one vehicle stopping at the intersection is counted as one stop) gets higher which is bad, if the cycle time is too long then, the delay time of the vehicle at the intersection gets higher which is again bad. Since we have both the stops and the delay as our outputs, this was given a careful consideration, as increasing input doesn't always result in increasing output in terms of delay and stops. This led to the following index that maintains the typical higher the input higher the output relationship while representing all the influencing factors appropriately.

It is generally agreed and can also be mathematically proven based on the philosophy of demand-based supply, that the optimum time interval for any movement should fulfill the following criteria. For i=1,2,3 or 4, g_{iL}, g_{iT} and g_{iR} represent the green times for the left, through and right turn movements in i^{th} way respectively.

As defined earlier

$$V=\sum_{i=1}^{i=4} V_i \qquad \textbf{(3.4)}$$

$$V_i=V_{iL}+V_{iT}+V_{iR}$$

The following criteria should be fulfilled as the philosophy of demand-based supply is followed in allocating green times for each movement. The following equalities essentially means that the percentage of effective green time to the total cycle time for a movement should be equal to the percentage of demand (number of vehicles accessing the intersection for the specific movement) to the total demand. It may not be the case in reality, as the updating of the signal timings to the changing demands is not kept up to date.

$$\begin{aligned} g_{iL}/C&=V_{iL}/V \\ g_{iT}/C&=V_{iT}/V \\ g_{iR}/C&=V_{iR}/V \end{aligned} \qquad \textbf{(3.5)}$$

Let us introduce the terms TC_i and TC here.

$$TC_i = \frac{1}{V_i} \times \left((g_{iT} \times V_{iT}) + (g_{iR} \times V_{iR}) + (g_{iL} \times V_{iL})\right) \qquad \textbf{(3.6)}$$

The timing coefficient (TC) is calculated as follows

$$TC = \frac{1}{V} \sum_{i=1}^{i=4} \{V_i \times TC_i\} \qquad \textbf{(3.7)}$$

The higher the value of TC is more the effective green time that is given to the movements with higher demands. This is influenced by the cycle time as well as the phasing system while this basically represents the time slices awarded to each of the movements at the intersections. This also follows the basic production principle "higher the input, higher the output"

3.5 Outputs

As explained earlier depending on the planner's perspective, the total number of vehicles that accessed a particular intersection or the total number of vehicles that got through an intersection can be considered either an input or a desirable output. In the research presented here the total number of vehicles that made it through the intersection was taken to be a positive output of the intersection-production unit analogy.

3.5.1 Traffic Characteristic: The number of vehicles from various approaches (V)

Traffic characteristics are characteristics such as the number of vehicles in each approach, the percentage of trucks and RVs in each approach, number of left turning vehicles in each approach, number of right turning vehicles in each approach, number of through vehicles in each approach. In analysis of any system, the analysis of bottlenecks is very critical. In the case of intersections, the bottlenecks are the peak hours during which the maximum number of vehicles is trying to use the system. So, It was decided that the all of the intersection data for the morning two-hour peak periods would be used for this model. As result of that, the total number of vehicles that got through the intersection in the peak hour that is of utmost importance to the planners is used as the positive output of four way signalized intersections.

This is a characteristic that should be considered a positive output. All the intersections considered are four ways. The positive output is the sum of the volumes of equivalent PCU (Passenger Car Units) s of vehicles arriving in the peak two hours of all the four ways. This includes all of the left, right and through movement vehicles on all four ways. The volume in each way is represented by V_1, V_2, V_3, and V_4. PCU is the unit that is used to represent the high profile vehicles in terms of the passenger cars to simplify the traffic related analysis. In this case, the volumes for each movement were produced in PCU units straight away.

V_i is where i= 1,2,3 or 4 is the sum of the following for the corresponding value of i.

V_{iL} (The number of left turning vehicles i^{th} way), V_{iT}, (The number of through vehicles i^{th} way) and V_{iR} (The number of right turning vehicles i^{th} way).

This can be represented as follows

$$V=\sum_{i=1}^{i=4} (V_{iL} + V_{iR} + V_{iT}) \tag{3.8}$$

3.5.2 Traffic Characteristic: Total Delay Per Vehicle (VD)

The time between the vehicle stopping at an intersection and the vehicle leaving the intersection is the delay that is being considered here. This is a measure of the traffic conditions at an intersection that cannot be directly measured on the field. On the other hand, it can be estimated from the data collected through the loop detectors. It can also be estimated from other parameters using the standard models that are available [1,3]. There are various models in the literature to calculate the total delay [3]. The following model that is explained here is the one that is presented in the textbook titled “Traffic Engineering” by McShane, W.R., and Roess, R.P. (1990).

$$D = \frac{\sum_{j=L,T,R} \sum_{i=1}^{4} d_{ij}' * V_{ij}}{V} \tag{3.9}$$

$$d_{ij}' = 0.9\left(d_{ij} + \frac{x_{ij} * x_{ij}}{2 * \lambda * (1 - x_{ij})} \right) \tag{3.10}$$

$$d_{ij} = \frac{(r_{ij} * r_{ij})}{(2 * C(1 - V_{ij} / S_{ij}))} \tag{3.11}$$

$$x_{ij} = \frac{V_{ij} * C}{S_{ij} * G_{ij}} \quad \textbf{(3.12)}$$

G_{ij} is the green interval for the j^{th} movement in the i^{th} approach.

S_{ij} is the saturation flow for the j^{th} movement in the i^{th} approach.

V_{ij} is the equivalent traffic volume for the j^{th} movement in the i^{th} approach.

$$\mathrm{VD} = \sum_{j=L,T,R} \sum_{i=1}^{4} d_{ij}' * V_{ij} \quad \textbf{(3.13)}$$

VD is used here as the undesirable output that would increase with the increase in positive outputs.

3.5.3 Traffic Characteristic: Number of stops per vehicle (NS)

The average number of stops per vehicle an intersection is the ratio of total number of stops to the total vehicle volume at the intersection. One stop is defined as one vehicle from any of the movements coming to a halt before crossing the intersection. This is a measure of traffic conditions. Obtaining this data through observation is very labor intensive. This measure can be estimated through the simulation of respective intersections for the peak hour traffic. There are no determinitistic models that were found in the literature survey. This is explained further in Chapter5 as potential future research.

There are various PC based micro simulation models in the literature through which the estimation of the number of stops is possible. Number of stops and the total delay are not directly correlated. Total number of stops per vehicle represents how many vehicles had to come to a halt before crossing the intersection while the total delay represents how long the vehicle that were halted had to be wait in the intersection and not how many vehicles had to stop.

3.6 Models

The next step to the determination of appropriate inputs and outputs for four way intersections is to choose one or more models from the set of well established and tested DEA models that are currently used in the industry for comparison and ranking purposes. There are two sets of DEA models as explained in Chapter 2. One set of models dwell on the concept of producing the same amount of outputs as present level with the amount of inputs used by the best practice unit. The second set of models concentrate on producing the best practice outputs with the same amount of inputs as present.

In the following subsections, it is examined how the different types of models can be applied for this case.

In the following sections, the following terminology is used. It is presented here as a refresher even if they were presented in earlier chapters.

The BCC and CCR model does not distinguish between desirable and undesirable outputs. It is a common practice to use one of the following conversion techniques to account for the undesirable nature of an output.

1. k-Y_{ij} is one way converting the output. Here k >> Y_{ij}. Now, k-Y_{ij} is a quantity that increases with the decrease in Y_{ij} and decreases with increase in Y_{ij}. So, k-Y_{ij} is desirable equivalent of the undesirable output to some extent.
2. $(1/Y_{ij})$ is one of the other conversion methods that are commonly used. Here again higher the value of Y_{ij}, the lower the value of $(1/Y_{ij})$ and lower the value of Y_{ij} higher the value of $(1/Y_{ij})$. This again is desirable equivalent of undesirable output Y_{ij} to a certain extent.

Both the techniques may possibly bring in undesirable bias into the model that may not exactly reflect the real production process. This is one of the reasons why the Fair's index model and hyperbolic measure based model are being examined.

u_1 and u_2 are the weights attached to V (total volume of vehicles through the intersection) and (k-VD) (total vehicle delay for all the vehicles through the intersection).

v_1, v_2 and v_3 are the weights attached to N (total number of lanes), PC (Phasing Coefficient) and TC (timing coefficient).

y_{1j_0} is V of the DMU_0 and y_{2j_0} is VD of the DMU_0. y_{1j} and y_{2j} are V and (k-VD) of jth DMU.

x_{1j_0}, x_{2j_0} and x_{3j_0} are N, PC and TC of DMU_0 respectively. x_{1j} , x_{2j} and x_{3j} are N, PC and TC of jth DMU respectively. ε is set to 0.05 for all the formulations.

3.6.1 Input Oriented DEA Models as Applied to Intersections

The concept of relative efficiency is defined in Section 2.5. This forms the basis of DEA. The following gives the linear program for the CCR model described in Section 2.5.1.

The CCR Model

The data set includes fifty isolated intersections (n=50). This data was simulated as explained in Section 3.7.

$$
\begin{aligned}
&\max \quad h_0 = \sum_{r=1}^{2} u_r y_{rj_0} \quad for \quad DMU_0 \\
&subject \quad to \quad \sum_{i=1}^{3} v_i x_{ij_0} = 1 \\
&\sum_{r=1}^{2} u_r y_{rj} - \sum_{i=1}^{3} v_i x_{ij} \le 0 j = 1,2,3, \ldots 50 \\
&v_i \quad \ge \varepsilon \quad i = 1,2, \ and 3 \\
&u_r \quad \ge \varepsilon \quad r = 1 and 2
\end{aligned}
\tag{3.14}
$$

The results of this modeling effort are presented in Chapter 4. This formulation was run in DEA Solver Learning Version 1.0.

The BCC Model

The BCC model has another constraint added to the envelopment form of CCR Model (2.7). This constraint is that the sum of all λ s should be equal to 1 ($\sum_{j=1}^{n} \lambda_j = 1$).

$$
\begin{aligned}
&\min \quad z_0 - \varepsilon \sum_{r=1}^{2} s_r^+ - \varepsilon \sum_{i=1}^{3} s_i^- \quad for \quad DMU_0 \\
&subject \quad to \quad x_{ij_0} z_0 = \sum_{j=1}^{n} x_{ij} \lambda_j + s_i^- \quad i = 1,2 \text{ and } 3 \\
&\sum_{j=1}^{50} y_{rj} \lambda_j = y_{rj_0} + s_r^+ \quad r = 1 \text{ and } 2 \\
&e\lambda = \sum_{j=1}^{50} \lambda_j = 1 \\
&\lambda_j \quad \ge 0 \ j = 1,2,3,4,\ldots\ldots,50 \\
&s_r^+ \quad \ge 0 \ r = 1 \text{ and } 2 \\
&s_i^- \quad \ge 0 \ i = 1,2 \text{ and } 3 \\
&z_0 \quad unconstrained
\end{aligned}
\tag{3.15}
$$

The results of this model are presented in Chapter 4. Both the models above assume constant returns to scale (CRS) and they have their objective as reducing the inputs holding the outputs constant.

3.6.2 Färe's Index Model as Applied to Intersections

This model does not assume constant returns to scale. It allows varying returns to scale (increasing or decreasing). This model also distinguishes between desirable outputs and undesirable outputs. The following notations used in the following formulation. They are consistent with the earlier citing.

$$
\begin{aligned}
x &= (x_1(N),\ x_2(PC),\ x_3(TC)) \in \Re^3_+ \\
p &= (p_1(V)) \in \Re^1_+ \\
q &= (q_1(VD)) \in \Re R^1_+ \\
y &= (p,\ q) \in \Re^{1+1}_+
\end{aligned}
\qquad \textbf{(3.16)}
$$

Q_p is calculated with the following linear program.

$$
\begin{aligned}
&(D_p(x^0,\ p^{k'},\ q^0))^{-1} = \max\ \theta \\
&s.t.\ \sum_{k=1}^{50} z_k p_1^k \geq \theta p_1^{k'}\ (k' \text{ represents the DMU under consideration}) \\
&\qquad \sum_{k=1}^{50} z_k q_1^k = q_1^0 \\
&\sum_{k=1}^{50} z_k x_1^k \leq x_1^0 \\
&\sum_{k=1}^{50} z_k x_2^k \leq x_2^0 \\
&\sum_{k=1}^{50} z_k x_3^k \leq x_3^0 \\
&z_k \geq 0,\ k = 1,\ldots 50
\end{aligned}
\qquad \textbf{(3.17)}
$$

Similarly, the following linear program calculates the distance function for undesirable outputs (Q_q).

$$
\begin{aligned}
&(D_q(x^0,\ p^0,\ q^{k'}))^{-1} = \min\ \lambda \\
&s.t. \sum_{k=1}^{50} z_k p_1^k \geq p_1^0 \\
&\sum_{k=1}^{50} z_k q_1^k = \lambda q_1^{k'} \\
&\sum_{k=1}^{50} z_k x_1^k \leq x_1^0 \\
&\sum_{k=1}^{50} z_k x_2^k \leq x_2^0 \\
&\sum_{k=1}^{50} z_k x_3^k \leq x_3^0 \\
&z_k \geq 0,\ k = 1,...50
\end{aligned}
\qquad \textbf{(3.18)}
$$

After the computation of these two quantity indexes, the environmental index is calculated as follows.

$$E^{k,l}(x^0,\ p^0,\ q^0,\ p^{k'},\ q^{k'}) = \frac{Q_p}{Q_q} \qquad \textbf{(3.19)}$$

Closer the value of the $E^{k,l}(x^0,\ p^0,\ q^0,\ p^{k'},\ q^{k'})$ more efficient the DMU is.

3.6.3 Hyperbolic Efficiency Measure Based Model Applied to Intersection

This model is based on increasing desirable output while the undesirable output is decreased. This is incorporated into the model in such a way that both the outputs change by the same proportion but in different directions.

$$
\begin{aligned}
&E_1^S(p_k,\ q_k,\ x_k) \ = \ \max[\theta \ : \ (\theta p_k,\ \theta^{-1} q_k) \ \in \ R^S(x_k)] \\
&s.t. \\
&\theta p_k \ \leq \ Pz \\
&q_k \ / \ \theta \ \leq \ Qz \\
&Xz \ \leq \ x_k \\
&z \ \in \ \Re_+^K
\end{aligned}
\qquad \textbf{(3.20)}
$$

The linear program above assumes strong disposability of undesirable outputs. And the notations mean as follows.

$$
P = \begin{matrix} p_1^1 \\ p_1^2 \\ p_1^3 \\ \vdots \\ p_1^{50} \end{matrix} \quad Q = \begin{matrix} q_1^1 \\ q_1^2 \\ q_1^3 \\ \vdots \\ q_1^{50} \end{matrix} \quad Z^T = \begin{matrix} z_1^1 \\ z_1^2 \\ z_1^3 \\ \vdots \\ z_1^{50} \end{matrix} \quad X = \begin{matrix} x_1^1 & x_2^1 & x_3^1 \\ x_1^2 & x_2^2 & x_3^2 \\ x_1^3 & x_2^3 & x_3^3 \\ \vdots & \vdots & \vdots \\ x_1^{50} & x_2^{50} & x_3^{50} \end{matrix} \qquad \textbf{(3.21)}
$$

The following linear program assumes a weak disposability of undesirable outputs. This is done to verify whether there is any congestion present. If the results for both these formulations are same then, there is no congestion present. If they are different then, the weak disposability is confirmed.

$$
\begin{aligned}
&E_1^W(p_k, q_k, x_k) = \max[\theta : (\theta p_k, \theta^{-1} q_k) \in R^W(x_k)] \\
&s.t. \\
&\theta p_k \leq Pz \\
&q_k / \theta = Qz \\
&Xz \leq x_k \\
&z \in \Re_+^K
\end{aligned}
\qquad \textbf{(3.22)}
$$

The "=" sign used for the undesirable output signifies the weak disposability of undesirable outputs.

In the above linear programs, the constraints for the desirable and the undesirable outputs have a '≤' which accounts for the strong disposability of both the outputs. Since the above program is nonlinear in θ, the problem cannot be solved by linear programming techniques. Färe (1989) proposed the following expression, which is linear in θ as a linear approximation to the nonlinear constraint. The assumption behind this is that θ can take a value greater than 1 (one) and it converges at $\theta = 1$.

$$2q_k - \theta q_k \leq Qz \qquad \textbf{(3.23)}$$

This approach has some drawbacks. The linear approximation and the nonlinear constraint are equal only for $\theta = 1$. Also as the value of θ diverges from one, the linear approximation diverges from the actual nonlinear constraint and hence the approximation error increases.

The following approximation works around this drawback.

$$(q_{tk} / \theta \leq \sum_{k=1}^{K} q_{tk} z_k)^{-1} \qquad \textbf{(3.24)}$$

This can equivalently be expressed as follows that is linear in θ,

$$\theta(q_{tk})^{-1} \geq (\sum_{k=1}^{K} q_{tk} z_k)^{-1} \qquad \textbf{(3.25)}$$

The results of these all of the above models are presented and discussed in Chapter 4.

3.7 Data Sets

Since it was not possible to get comprehensive data on isolated intersections from the agencies, the data on isolated intersections were created by simulation. The simulation exercise is described as follows.

3.7.1 Simulating Volume Data

V_i where i= 1,2,3 or 4 is the sum of the following three variables.

1) V_{iL} (The number of left turning vehicles i^{th} way)
2) V_{iT}, (The number of through vehicles i^{th} way) and
3) V_{iR} (The number of right turning vehicles i^{th} way)

V_{iL}, V_{iT}, V_{iR} for i=1,2,3 and 4 are created in the following manner. At first a random variable that varies between one and zero is created using the random variable function in MS Excel for each of the twelve volume variables. Using this random variable as the probability and using the cumulative probability density function of a normally distributed random variable with an average of 400,1200 and 400 for left, through and right turning vehicles respectively is found out for each of those twelve volume variables.

3.7.2 Simulating Infrastructure Data

N_i where i= 1,2,3 or 4 is the sum of the following three entities.

1) N_{iL} (The number of left turning vehicles i^{th} way),
2) N_{iT}, (The number of through vehicles i^{th} way) and
3) N_{iR} (The number of right turning vehicles i^{th} way).

N_{iL}, N_{iT}, N_{iR} for i=1,2,3 and 4 are created in the following manner. At first a random variable that varies between one and zero is created using the random variable function in MS Excel for each of the twelve Lane variables. Using this random variable as the probability and using the cumulative probability density function of a normally distributed random variable with an average of 1,2 and 1 for left, through and right turning lanes respectively is found out for each of those twelve volume variables.

3.7.3 Simulating Phasing data

A set of most commonly found phasing systems was identified and a phasing system from that set was randomly chosen. This set would have phasing systems with number of phases ranging [3,6]. This set had 6 phasing systems as described below. The saturation flows for the calculation were as follows. These values were chosen from the literature. These values should be changed according to the field conditions.

When $N_{iL} = 0$; $N_{iT} = 1$; $N_{iR} = 0$;
S_i=1700

When $N_{1L} = 1$; $N_{1T} = 1$; $N_{1R} = 0$
S_{iL}=1613; S_{iTR}=1800

When $N_{iL} = 0$; $N_{iT} = 2$; $N_{iR} = 0$
S_i=3400

When $N_{iL} = 1$; $N_{iT} = 2$; $N_{iR} = 0$
S_{iL}=1613; S_{iTR}=3600

When $N_{iL} = 0$; $N_{iT} = 3$; $N_{iR} = 0$
S_i=5100

When $N_{iL} = 1$; $N_{iT} = 3$; $N_{iR} = 0$
S_{iL}=1613; S_{iTR}=5400

When $N_{iL} = 0$; $N_{iT} = 1$; $N_{iR} = 1$

S_{iLT}=1700; S_{iR}=1613

When $N_{iL} = 1$; $N_{iT} = 1$; $N_{iR} = 1$

S_{iL}=1613; S_{iT}=1800; S_{iR}=1613

When $N_{iL} = 0$; $N_{iT} = 2$; $N_{iR} = 1$

S_{1iLT}=3400; S_{1iR}=1613

When $N_{iL} = 1$; $N_{iT} = 2$; $N_{iR} = 1$

S_{iL}=1613; S_{iT}=3600; S_{iR}=1613

When $N_{iL} = 0$; $N_{iT} = 3$; $N_{iR} = 1$

S_{iLT}=5100; S_{iR}=1613

When $N_{1iL} = 1$; $N_{1iT} = 3$; $N_{1iR} = 1$

S_{iL}=1613; S_{iT}=5400; S_{iR}=1613

The six phasing systems that are commonly found and chosen to be randomly picked for all the intersections that were created for this study are presented in appendix A.

The random selection of a phasing system is done in the following manner. At first a random variable that varies between one and zero is created using the random variable function in MS Excel.

Then, Using this random variable as the probability and using the cumulative probability density function of a normally distributed random variable following standard normal distribution, a phasing system is chosen from the set of six phasing systems identified and described in appendix A.

Every phasing system in that set has a number that represents the number of phases associated with that. That is how the number of phases is randomly generated. The phasing coefficient (PC) is calculated as follows. Using the following formulae described in the earlier section, expressions of PC for all the phasing systems is kept ready associated with them. Once the phasing system has been chosen, the variables (volume of vehicles in conflict) in the expression of PC for that phasing system are substituted and the value of PC is calculated.

3.7.4 Simulating Timing Data

At first a random variable that varies between one and zero is created using the random variable function in MS excel. Then, Using this random variable as the probability and using the cumulative probability density function of a normally distributed random variable with an average of 160 and with a range of [80,240], a cycle length (C_c) is chosen.

g_{iL}, g_{iT} and g_{iR} represent the green times for the left, through and right turn movements in i th way respectively. Before calculating TC, the time intervals for each movement need to be created.

3.7.5 Simulating Delay

All the variables required are simulated in a controlled random fashion as described above. Calculating the delay is straight forward as all the variables required for the calculation are available from the set of data simulated as described in Sections 3.7.1 to 3.7.4 from. This is done using the equations 3.9 to 3.13.

3.7.6 MS Excel Functions Used in Simulation

The following functions from MS Excel were used for the normal distribution functions in the creation of the data as explained above. The Function NORMDIST returns the normal cumulative distribution for the specified mean and standard deviation. This function has a very wide range of applications in statistics, including hypothesis testing.

NORMDIST (x, mean, standard_dev, cumulative)
X is the value for which you want the distribution.
Mean is the arithmetic mean of the distribution. Standard_dev is the standard deviation of the distribution. Cumulative is a logical value that determines the form of the function. If cumulative is TRUE, NORMDIST returns the cumulative distribution function; if FALSE, it returns the probability mass function. If mean or standard_dev is nonnumeric, NORMDIST returns the #VALUE! error value. If standard_dev ≤ 0, NORMDIST returns the #NUM! error value. If mean = 0 and standard_dev = 1, NORMDIST returns the standard normal distribution, NORMSDIST. The equation for the normal density function is

$$f(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\left(\frac{(x-\mu)^2}{2\sigma^2}\right)} \qquad \textbf{(3.26)}$$

NORMDIST (42,40,1.5,TRUE) equals 0.908789

3.8 Programming and Model Implementation

Both the input reducing models were solved using the MS excel based DEA Solver-LV package.

The Färe's index model and the hyperbolic model were programmed in MS Excel using the linear program solver that is present in Excel. The details of these programs are provided in Appendix B.

Chapter 4. Results and Discussion

This chapter discusses the results that were obtained as part of the modeling effort. There were two models that were run as part of this research. There are two sections that present the results obtained from the fare's index model and hyperbolic efficiency measure. The third section will compare and contrast the results of these two models.

4.1 Tests on the Data Set

If the variables are strongly correlated, the solving of linear program gets inefficient. To verify how related are the five variables used in the models here, linear correlation coefficients were calculated using the following formulae.

$$r^2 = \frac{\left[\sum_i (x_i - \bar{x})\ (y_i - \bar{y})\right]^2}{\sum_i (x_i - \bar{x})^2\ \sum_i (x_i - \bar{y})^2} \qquad \textbf{(4.1)}$$

r – coefficient of linear correlation

$\bar{x}$ - Mean of variable x

$\bar{y}$ - Mean of variable y

	Output 1(V)	Input 1 (N)	Input 2 (PC)	Input 3 (TC)	Output 2 (VD)
Output 1(V)	1	0.53	0.60	0.17	0.08
Input 1 (N)	0.53	1	0.27	0.02	0.05
Input 2 (PC)	0.60	0.27	1	0.68	0.10
Input 3 (TC)	0.17	0.02	0.68	1	0.18
Output 2 (VD)	0.08	0.05	0.10	0.18	1

Table 4.1 Correlation coefficient of variables with each other

The above correlation coefficients show that there is no significant correlation among the inputs and among the outputs. The compliance of the process of vehicles getting through an intersection to the production axioms has been verified in Chapter 3 while the indices and parameters are introduced by checking whether all the inputs have directly proportional relationship with all the outputs.

4.2 Level of Service from HCM 2000

The levels of service of all the intersections in the model were calculated according to HCM 2000. This LOS list is used to explain the results from the DEA models.

Intersection (DMU)	Avg. Delay in seconds/ Vehicle (over all four ways)	LOS (Based on HCM 2000)
2	2.90	A
3	15.79	B
5	7.14	A
6	40.16	D
7	10.96	B
8	7.74	A
9	25.01	C
10	10.70	B
11	184.55	F
12	14.82	B
13	5.65	A
14	3.82	A
15	32.29	C
16	3.99	A
17	10.78	B
18	18.68	B
19	88.15	F
20	122.93	F
21	7.51	A
22	68.94	E
23	15.28	B
24	15.03	B
25	54.20	D
26	15.67	B
27	18.58	B
55	1.29	A
29	27.92	C
30	47.63	D
31	4.73	A
32	12.24	B
33	173.18	F
34	33.49	C
35	36.93	D
36	14.15	B

37	16.93	B
38	8.94	A
39	89.90	F
40	19.47	B
41	21.13	C
42	9.93	A
43	34.27	C
44	48.11	D
46	25.29	C
47	43.99	D
48	31.91	C
49	30.42	C
51	31.93	C
52	32.18	C
53	76.05	E
54	5.95	A

Table 4.2 Average Delays and Level of Service from HCM 2000

From the above table, it could be stated that the following set of intersections are servicing the vehicles in the best manner in terms of delay per vehicle.

Intersection (DMU)
2
5
8
13
14
16
21
31
38
42
54

Table 4.3 Intersections with a Level of Service A

We compare these intersections shown to be servicing the vehicles in the best possible manner from the calculation of levels of service, these results will be compared to the ones from fare’s index and hyperbolic measure based models.

4.3 Results from the input oriented Models

Both of the input oriented models CCR and BCC required the undesirable output to be converted to other forms as explained in Chapter 3. The results presented below uses the (k-VD) conversion, as this was considered appropriate than the other technique (1/VD). The value of k is required to be much larger than the values of VD. It was felt appropriate the effect of largeness of k on the results of these models. For this purpose, the following two scenarios were tested.

1) k= 2 x the maximum value of VD in the data set
2) k= 10 x the maximum value of VD in the data set

The results of these two scenarios are presented and compared below.

4.3.1 Results from the Input Reducing CCR Model

The first column in the table below represents the given DMU number. The scores are the efficiency scores from the input reducing Charnes, Cooper and Rhodes Model. The rank is based on the descending order of the efficiency score. The intersections with higher rank are functioning with higher production efficiency.

DMU	Score		Rank	
	When k= 10*maximum of VD	When k= 2*maximum of VD	When k= 10*maximum of VD	When k= 2*maximum of VD
54	0.68	0.81	39	33
53	0.90	0.89	17	21
52	0.84	0.85	27	27
51	0.92	0.92	13	15
49	0.82	0.88	30	22
48	0.88	0.89	19	20
47	1	1	1	1
46	0.74	0.76	34	39
44	0.87	0.87	22	25
43	0.84	0.87	26	26
42	0.88	1	20	1
41	0.85	0.90	24	17
40	1	1	1	1

39	1	1	1	1
38	0.60	0.66	49	47
37	0.90	0.92	16	16
36	0.73	0.77	36	37
35	0.79	0.80	32	34
34	0.85	0.85	25	29
33	0.89	0.89	18	19
32	0.90	0.95	15	13
31	0.69	0.78	38	36
30	0.67	0.73	41	41
29	0.83	0.85	28	28
28	1	1	1	1
27	0.64	0.72	45	43
26	0.96	0.97	10	11
25	0.90	0.90	14	18
24	0.99	1	8	1
23	0.92	0.95	12	14
22	1	1	1	1
21	0.77	0.82	33	31
20	0.85	0.81	23	32
19	1	1	1	1
18	0.62	0.65	46	48
17	0.81	0.85	31	30
16	0.66	0.70	42	44
15	0.87	0.88	21	24
14	0.74	0.80	35	35
13	0.65	0.75	44	40
12	0.61	0.67	47	46
11	0.61	0.60	48	50
10	0.65	0.76	43	38
9	0.93	0.97	11	10
8	0.82	0.88	29	23
7	0.58	0.63	50	49
6	0.96	0.96	9	12
5	1	1	1	1
3	0.68	0.69	40	45
2	0.70	0.72	37	42

Table 4.4 Efficiency Scores and ranks from input reducing CCR Model when k value used for conversion is changed

Peers for k=2*max VD	Peers for k=10*max VD
47	47
42	40
40	39

39	28
28	22
24	19
22	5
19	
5	

Table 4.5 Peers from input reducing CCR Model when k value used for conversion is changed

It is found that the intersections that form the efficiency frontier do not change drastically by the change in the value of k. Intersection 42 alone drops out of the frontier when the k value is increased. One should note that these models use the constant returns to scale (CRS). Even though intersection 47 is not performing at an LOS of A, it turns to be performing at best in terms of production efficiency. The reason for this is the fact that 47 is moving 9864 vehicles with 426074.3 seconds of total delay compared to intersection 25 that moves comparable number of vehicles to that of intersection 47 has 1.25 times of delay and there are not other intersections with number of vehicles comparable to 47. This makes 47 part of efficiency frontier.

It is seen here that intersections with LOS of A to F are part of the efficiency frontier. This reinforces the discussion of the inability of LOS to distinguish between inefficient intersections due to poor resource allocation or for dearth of enough resources and inefficient intersections due to excessive demand leading to excessive delays.

4.3.2 Results from the Input Reducing BCC Model

The following table presents the results from input reducing BCC model. Here again the model was tested for the influence of the value of k. The notations here are consistent with earlier tables in this chapter.

DMU	Score		Rank	
	When k= 10*maximum of VD	When k= 2*maximum of VD	When k= 10*maximum of VD	When k= 2*maximum of VD
54	0.90	0.90	29	29
53	0.90	0.90	30	30
52	0.87	0.87	37	37
51	1	1	1	1
49	0.89	0.89	33	33
48	0.89	0.89	32	32
47	1	1	1	1
46	0.93	0.93	24	24
44	0.87	0.87	35	35
43	0.90	0.901	28	28
42	1	1	1	1
41	0.90	0.90	27	27
40	1	1	1	1
39	1	1	1	1
38	0.75	0.75	45	45
37	1	1	1	1
36	0.85	0.85	39	39
35	0.83	0.83	42	42
34	0.86	0.86	38	38
33	0.90	0.90	26	26
32	0.96	0.96	22	22
31	1	1	1	1
30	0.73	0.73	46	46
29	0.87	0.87	34	34
28	1	1	1	1
27	0.79	0.79	44	44
26	1	1	1	1
25	1	1	1	1
24	1	1	1	1
23	1	1	1	1
22	1	1	1	1
21	0.89	0.89	31	31
20	0.87	0.87	36	36
19	1	1	1	1
18	0.71	0.71	48	48
17	0.94	0.94	23	23
16	0.97	0.97	20	20
15	0.91	0.91	25	25
14	1	1	1	1
13	0.85	0.85	41	41
12	0.70	0.70	49	49
11	0.62	0.62	50	50
10	0.85	0.85	40	40

9	1	1	1	1
8	1	1	1	1
7	0.72	0.72	47	47
6	0.96	0.96	21	21
5	1	1	1	1
3	0.82	0.82	43	43
2	1	1	1	1

Table 4.6 Efficiency Scores and ranks from input reducing BCC model when k value used for conversion is changed

Peers for k=2*max VD	Peers for k=10*max VD
51	51
47	47
42	42
40	40
39	39
37	37
31	31
28	28
26	26
25	25
24	24
23	23
22	22
19	19
14	14
9	9
8	8
5	5
2	2

Table 4.7 Peers from input reducing BCC model when k value used for conversion is changed

It is again found here that the intersections that form the efficiency frontier do not change with the change in the value of k for this data set for input reducing BCC Model.

4.3.3 Results from the Output Increasing CCR Model

The following table presents you with the results from output increasing CCR model. As indicated in Chapter 2, both these models are based on constant returns to scale and they do not distinguish between desirable outputs and undesirable outputs.

DMU	Score		Rank	
	When k= 10*maximum of VD	When k= 2*maximum of VD	When k= 10*maximum of VD	When k= 2*maximum of VD
54	0.68	0.81	39	33
53	0.90	0.89	17	21
52	0.84	0.85	27	27
51	0.92	0.92	13	15
49	0.82	0.88	30	22
48	0.88	0.89	19	20
47	1	1	1	1
46	0.74	0.76	34	39
44	0.87	0.87	22	25
43	0.84	0.87	26	26
42	0.88	1	20	1
41	0.85	0.90	24	17
40	1	1	1	1
39	1	1	1	1
38	0.60	0.66	49	47
37	0.90	0.92	16	16
36	0.73	0.77	36	37
35	0.79	0.80	32	34
34	0.85	0.85	25	29
33	0.89	0.89	18	19
32	0.90	0.95	15	13
31	0.69	0.78	38	36
30	0.67	0.73	41	41
29	0.83	0.85	28	28
28	1	1	1	1
27	0.64	0.72	45	43
26	0.96	0.97	10	11
25	0.90	0.90	14	18
24	0.99	1	8	1
23	0.92	0.95	12	14
22	1	1	1	1
21	0.77	0.82	33	31
20	0.85	0.81	23	32
19	1	1	1	1
18	0.62	0.65	46	48
17	0.81	0.85	31	30
16	0.66	0.70	42	44

15	0.87	0.88	21	24
14	0.74	0.80	35	35
13	0.65	0.75	44	40
12	0.61	0.67	47	46
11	0.61	0.60	48	50
10	0.65	0.76	43	38
9	0.93	0.97	11	10
8	0.82	0.88	29	23
7	0.58	0.63	50	49
6	0.96	0.96	9	12
5	1	1	1	1
3	0.68	0.69	40	45
2	0.70	0.72	37	42

Table 4.8 Efficiency Scores and ranks from output increasing CCR model when k value used for conversion is changed

Peers when k=2*max VD	Peers when k=10*max VD
47	47
42	40
40	39
39	28
28	22
24	19
22	5
19	
5	

Table 4.9 Peers from output increasing CCR model when k value used for conversion is changed

Here we see the effect of changing the value of k. When the value of k is increased by a factor of 5, it is seen that intersections 42 and 24 are no longer in the efficiency frontier. It should again be kept in mind that these models are based on constant returns to scale, which brings in scale sensitivity to these models. Even though these two intersections are not in the frontier, they still have efficiency scores of 0.88 and 0.99 respectively.

4.3.4 Results from the Output Increasing BCC Model

The following table has the results from output increasing BCC model. The notations in this table are consistent with earlier notations in this chapter.

DMU	Score		Rank	
	When k= 10*maximum of VD	When k= 2*maximum of VD	When k= 10*maximum of VD	When k= 2*maximum of VD
54	0.99	0.99	21	21
53	0.96	0.89	47	48
52	0.98	0.85	42	43
51	1	0.92	1	1
49	0.99	0.88	36	39
48	0.99	0.89	39	38
47	1	1	1	1
46	0.98	0.76	43	35
44	0.97	0.87	46	47
43	0.98	0.87	41	42
42	1	1	1	1
41	0.99	0.90	33	34
40	1	1	1	1
39	1	1	1	1
38	0.99	0.66	26	26
37	1	0.92	1	1
36	0.99	0.77	28	29
35	0.98	0.80	44	44
34	0.98	0.85	40	41
33	0.93	0.89	49	45
32	0.99	0.95	25	25
31	1	0.78	1	1
30	0.98	0.73	45	46
29	0.99	0.85	37	37
28	1	1	1	1
27	0.99	0.72	35	36
26	1	0.97	1	1
25	1	0.90	1	1
24	1	1	1	1
23	1	0.95	1	1
22	1	1	1	1
21	0.99	0.82	23	23
20	0.94	0.81	48	49
19	1	1	1	1
18	0.99	0.65	38	40
17	0.99	0.85	24	24
16	0.99	0.70	20	20
15	0.99	0.88	31	30
14	1	0.80	1	1
13	0.99	0.75	22	22
12	0.99	0.67	30	32
11	0.90	0.60	50	50

10	0.99	0.76	27	27
9	1	0.97	1	1
8	1	0.88	1	1
7	0.99	0.63	29	31
6	0.99	0.96	32	28
5	1	1	1	1
3	0.99	0.69	34	33
2	1	0.72	1	1

Table 4.10 Efficiency Scores and ranks from input reducing BCC model when k value used for conversion is changed

The efficiency scores from various models will be compared to each other in Section 3.6.

Peers when k=10 *Max VD	Peers when k=2 *Max VD
51	51
47	47
42	42
40	40
39	39
37	37
31	31
28	28
26	26
25	25
24	24
23	23
22	22
19	19
14	14
9	9
8	8
5	5
	2

Table 4.11 Peers from output increasing BCC model when k value used for conversion is changed

The above table shows that output-increasing model adds more intersections to the efficiency frontier. This can be attributed to the fact that the model is based on increasing the outputs for given inputs and there is not too much variability in the values of outputs.

4.4 Results from Färe's Index Model

The following table presents the results from the Färe's index model presented in Chapter 3. Table 4.12 presents the quantity indices and the efficiency score as defined in equation 3.19. The ranks are based on the efficiency score (closer the value of E to 1, the higher the rank is). This rank here indicates the best performance ranking in terms of production efficiency. One way to rank these intersections in terms of need for improvement is to reverse the ranking from descending order to ascending order of efficiency scores.

It should be noted that intersections 39,33 and 11 lie out of feasible solution region when the linear program for desired quantity index of these intersections is implemented. This can be explained by the fact that the intersections 39,33, 19 and 11 have the undesired output (total vehicle delay VD) at ratios of 2.715, 4.821, 2.5 and 5.629 times the average value of VD for all the intersections in the model. These huge numbers for this undesirable output pushed these three intersections out of the feasible region defined by the empirical desirable output frontier formed by the model. It should also be clear that these high ratio of undesirable output to average value of the same is not the only reason as that is not the only measure that defines the feasible region. The model formulates this region.

DMU	Qp	Qp	E	Rank
54	1.24	0.56	0.45	23
53	1.41	0.18	0.13	42
52	1.17	0.36	0.30	29
51	1	0.84	0.84	15
49	1.515065	0.13	0.08	45
48	1.159843	0.45	0.38	26
47	1	1	1	1
46	1.086111	0.16	0.15	41
44	1.266334	0.24	0.19	37
43	1.147448	0.31	0.27	30
42	1	1	1	1
41	1.296909	0.24	0.19	38
40	1	1	1	1
39	0	1	N/A	None
38	1.42666	0.32	0.22	34
37	1	1	1	1

36	1.16	0.41	0.35	27
35	1.23	0.19	0.15	40
34	1.20	0.31	0.26	31
33	0	0.06	N/A	None
32	1.07	0.58	0.54	18
31	1	1	1	1
30	1.48	0.07	0.04	47
29	1.22	0.27	0.22	35
28	1	1	1	1
27	1.31	0.16	0.12	43
26	1.01	1	0.98	13
25	1.15	0.47	0.41	25
24	1	1	1	1
23	1	0.91	0.91	14
22	1.16	0.27	0.23	33
21	1.22	0.62	0.502	20
20	1.21	0.09	0.07	46
19	N/A	N/A	N/A	None
18	1.43	0.15	0.10	44
17	1.03	0.66	0.64	17
16	1.09	0.87	0.79	16
15	1.07	0.50	0.47	22
14	1	1	1	1
13	1.23	0.63	0.51	19
12	1.45	0.27	0.18	39
11	0	0.021625	N/A	None
10	1.19	0.39	0.32	28
9	1.10	0.54	0.49	21
8	1	1	1	1
7	1.40	0.33	0.23	32
6	1.04	0.44	0.42	24
5	1	1	1	1
3	1.21	0.27	0.22	36
2	1	1	1	1

Table 4.12 Efficiency Scores and ranks from Färe's Index Model

The important information from any DEA model, are peers and performance goals as indicated earlier in Chapter 1 and 2. The peers for each intersection or the closest intersections that are efficient (peers) can be identified and performance goals for each of the intersections can be set from the best practice intersections (efficient peers). For example, let us consider intersection 54, one can determine that intersections 31, 42 and 5 are peers of intersection 54 using the table from Appendix C. 31 is the most efficient of these three. The output input matrix ({V, VD, N, PC, TC}) for intersections 54 and 31 are {5310, 31618.8, 1.61, 0.277, 21.7} and {6865, 32532.4, 1.66, 0.29, 15.5}. 54 moves more vehicles using less or comparable inputs with lesser VD/V ratio (average vehicle delay per vehicle). The problem areas for 54 could be identified as using more TC and less PC. So the phasing system and timing need to be modified and made appropriate to the vehicle demand for each movement.

This could even be simulated in readily available microscopic simulation software packages and verified what needs to be done in terms of phasing and timing. The performance goal for 54 is to move towards the best practice demonstrated by 31 for very similar conditions in terms of performance. The table below identifies the intersections that form the efficient frontier.

Peers from Färe's index Model
47
42
40
37
31
28
26
24
14
8
5
2

Table 4.13 Peers from Färe’s Index Model

Apart from the intersections that were shown to be efficient in the other models, intersections 37, 31, 14, 8 and 2 also form the frontier in fare’s index model. This model distinguishes between desirable and undesirable outputs. This makes the model robust in finding the efficient ones. It should also be noted that all these intersections (37, 31, 14, 8 and 2) operate at an LOS of A.

4.5 Results from Model Based on Hyperbolic Efficiency Measure

The model presented in Chapter 3 (equation 3.20) needs to be converted to a linear program. There are two approximations presented in Section 3.6.3. For this program to be run using the LP solvers in MS excel, it is necessary to use the following approximation.

$$2q_k - \theta q_k \le Qz$$

This approximation was used for the model based on the weak disposability and the model based on strong disposability of undesirable output. The results of these models are being presented in table 4.14.

DMU	E_1^S	Score	E_1^W	Score	Congestion	Rank (W)	Rank (S)
54	1.16	0.86	1.31	0.75	1.134474	21	40
53	1.36	0.73	1.36	0.73	1	20	44
52	1.15	0.86	1.15	0.86	1	19	30
51	1	1	1	1	1	2	1
49	1.43	0.69	1.43	0.69	1	36	49
48	1.14	0.87	1.14	0.87	1	15	28
47	1	1	1	1	1	1	1
46	1.07	0.92	1.07	0.92	1	8	23
44	1.22	0.81	1.22	0.81	1	24	36
43	1.13	0.88	1.13	0.88	1	17	26
42	1	1	1	1	1	1	1
41	1.22	0.81	1.22	0.81	1	28	37
40	1	1	1	1	1	1	1
39	N/A	N/A	N/A	N/A			
38	1.33	0.75	1.33	0.75	1	32	42
37	1	1	1	1	1	1	1
36	1.13	0.88	1.13	0.88	1	16	27
35	1.20	0.82	1.20	0.82	1	27	35
34	1.18	0.84	1.18	0.84	1	25	32
33	N/A	N/A	N/A	N/A			
32	1.06	0.94	1.06	0.94	1	7	21
31	1	1	1	1	1	1	1
30	1.41	0.70	1.41	0.70	1	35	47
29	1.20	0.83	1.20	0.83	1	26	34
28	1	1	1	1	1	1	1
27	1.29	0.77	1.29	0.77	1	31	39
26	1	0.99	1	0.99	1	1	17
25	1.12	0.88	1.12	0.88	1	10	25
24	1	1	1	1	1	1	1
23	1	1	1	1	1	1	1

22	1.15	0.86	1.15	0.86	1	11	29
21	1.16	0.85	1.31	0.75	1.12	13	41
20	1.25	0.79	1.25	0.79	1	29	38
19	N/A	N/A	N/A	N/A			
18	1.40	0.71	1.40	0.71	1	33	46
17	1.02	0.97	1.02	0.97	1	6	18
16	1.03	0.96	1.03	0.96	1	4	19
15	1.07	0.93	1.07	0.93	1	9	22
14	1	1	1	1	1	1	1
13	1.13	0.87	1.42	0.70	1.25	18	48
12	1.38	0.72	1.38	0.72	1	34	45
11	1.56	0.64	1.56	0.64	1	37	50
10	1.17	0.85	1.17	0.85	1	22	31
9	1.09	0.91	1.09	0.91	1	12	24
8	1	1	1	1	1	1	1
7	1.34	0.74	1.34	0.74	1	30	43
6	1.03	0.96	1.03	0.96	1	5	20
5	1	1	1	1	1	1	1
3	1.19	0.83	1.19	0.83	1	23	33
2	1	1	1	1	1	1	1

Table 4.14 Efficiency Scores and ranks from hyperbolic measure based model

It should be noted again those intersections 19, 33 and 39 lie outside of the feasible region in these models. This could be reasoned on the basis of the argument cited for the same in Färe’s index model.

Peers got from hyperbolic measure based model
51
47
42
40
37
31
28
24
23
14
8
5
2

Table 4.15 Peers from hyperbolic measure based model

51 and 23 that had efficiency scores close to 1 in fare's index model are shown to be on the efficiency frontier in the hyperbolic measure based model.

4.6 Comparison of Results

Since the CCR model and BCC models were run for verification of data and DEA demonstration purposes, the results of the 8 scenarios in total for 4 models are not compared in detail here.

Färe's index model and hyperbolic measure based model distinguish between desirable and undesirable outputs. They also allow for scales other than constant returns to scale. These two features have made us choose these two models for demonstrating DEA for ranking intersections for planning purposes.

Let us compare the intersections that form the efficiency frontiers.

Peers from Färe's index Model	Peers from hyperbolic measure based model
	51
47	47
42	42
40	40
37	37
31	31
28	28
26	
24	24
	23
14	14
8	8
5	5
2	2

Table 4.16 Comparison of Färe's and Hyperbolic models

From table 4.16, we see that hyperbolic model has intersections 51 and 23 and does not have intersection 26 in the frontier unlike the index model. Intersection 51 and 23 get efficiency scores of 0.8493 and 0.915 respectively and intersections 26 in hyperbolic model have an efficiency score of 0.990145. Even though intersection 51 is operating at a level of service of C, it gets high efficiency scores consistently across the two models. {V, VD, N, PC, TC} for intersection 51 is {5347, 170735.44, 2.043, 0.037, 46.50}.

The efficiency scores got from both models should be compared to see which model ranks the given data set effectively. The figure below depicts the difference between the three efficiency scores. The horizontal axis is the DMU number and the efficiency scores are not a continuous function over the DMU numbers. The curves are drawn just to depict where the results (efficiency scores from different models stand. The graph should be just looked at for the efficiency scores at discontinuous data points.

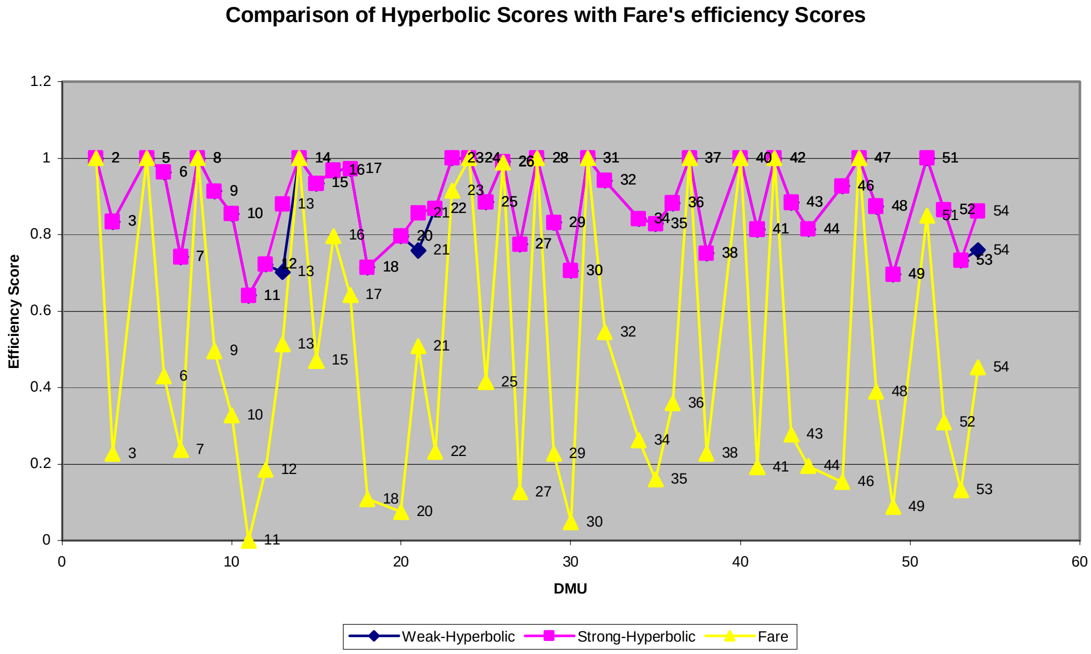

Figure 4.1 Comparison of hyperbolic and Färe’s index model efficiency scores

It is seen that the Färe’s index model formulation differentiates between the inefficient intersections more than hyperbolic. It is also shown that weak disposability and the strong disposability assumption for the hyperbolic models give out very similar efficiency scores meaning that the production process is not congested due to the weak disposability of undesirable output.

4.7 Summary of Results

Even though CCR and BCC models are not very appropriate to the ranking of intersections, these models were run to test whether the data was appropriate as a standard software package was used for running these two models. It was apparent that these models were effective to some extent in finding out the efficient intersections. It should be noted that the results got from the input reducing and the output increasing models of both BCC and CCR models were very much comparable.

Färe's index model and hyperbolic model were consistent with regards to their efficiency frontiers. Färe's scores had very high variability compared to hyperbolic measures. This can be explained with figure 2.7. This shows the difference between these two models. Since the hyperbolic measure tries to reduce the undesirable output while increasing the desirable output, the existence of congestion can be determined by evaluating the firm successively under strong and weak disposability assumptions. If the efficiency scores obtained from both the assumptions are the same, then the firm's production process is not affected by congestion. Hence the undesirable outputs can be reduced without any reduction in the desirable outputs. On the other hand, if the scores are different, then congestion is said to exist and weak disposability is binding.

It should also be noted that hyperbolic model tries to reduce the undesirable output by the same ratio as it increases the desirable ratio. The Färe's index model increases both the desirable and undesirable outputs by the same ratio.

Chapter 5. Conclusions and recommendations

The results that have been discussed in chapter 4 lead to the following conclusions. It is beneficial to use DEA as a model for planning the improvements of signalized intersections. Even though the application of DEA models for only a set of four way signalized intersections has been demonstrated here, it is feasible to do the same for signalized, two way stop controlled, all way stop controlled, or mixture of one or more types of these intersections with more than or less than four approaches.

5.1 Conclusions

It is feasible to model signalized intersections using the data envelopment method (DEA). This conclusion is derived from the fact that the data modeling of 50 such intersections was found to be significantly beneficial compared to the method of comparing them on the basis of level of services and the results presented in Chapter 4 are very encouraging.

It has been found that using DEA for the evaluation of signalized intersections proves to be effective than doing a capacity analysis and calculating levels of service, as there is no established effective way combining the results from these two for planning purposes. DEA modeling helps to combine the capacity analysis and the service estimation, two of the traditional processes in evaluation of single intersection evaluations for the purpose of system wide comparison, ranking and selection for improvements.

Further research need to be performed to see whether it is correct to compare intersections with different number of ways (i.e. other than just four ways). Once this is verified, a simplified interface for the agencies to create the inputs and outputs from their traditional data can be developed. This will facilitate the use of these models in a wide spread fashion.

5.2 Research Contributions

The representation of phasing system, timing system and other parameters of signalized intersections in a mathematical model are defined here. This is a first step in the direction of modeling intersections in terms of systems analysis tools.

The basic production theory axioms and other assumptions, on which DEA is based on, were verified in this study. This forms the basis for further studies on the evaluation of signalized intersections using Data Envelopment Analysis.

This research has identified the models that would fit the analogy that is explained in the chapter 2. It has also been demonstrated how various data conversions could affect the decision making in Chapters 3 and 4.

5. 3 Future Research

One step forward from what has been done as a part of this thesis is including the average number of stops per vehicle for an intersection. It may not be an economically viable practice to collect data on the number of stops in every intersection. There are very many models in practice for measuring the average number of stops per vehicle. One method that is used in Transyt 7F is presented here.

Stops are calculated similarly to the calculation of delays. Consider the arrival departure graph below. The total number of vehicles being delayed is equal to the number of vehicles queued or Q in the diagram above. However vehicles being delayed for less than 10 seconds do not make a full stop.

This suggests that one can use the model that is available for the calculation of number of delayed vehicles for each delay time and then count the vehicles that are delayed for more than 10 seconds. This model can be found in the literature.

Transyt 7F calculates the number of stopped vehicles by counting the number of delayed vehicles for each delay time and adjusting these vehicles by the following table:

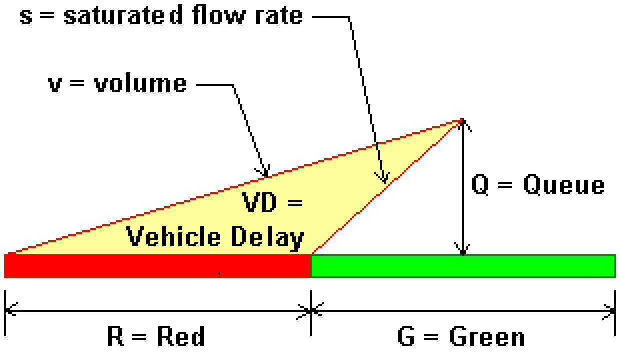

Figure 5.1 Arrival Departure Graph (Source: SYNCHRO help files)

Vehicle Delay (in seconds)	Percent of Stop
0	0%
1	20%
2	58%
3	67%
4	77%
5	84%
6	91%
7	94%
8	97%
9	99%

Table 5.1 the relationship between delays and percentage stops

This table was obtained from the TRANSYT 7-F Users guide.

These stops are calculated for each percentile scenario and averaged for cycle failures and over capacity vehicles. The stop calculations model 100 cycles similar to the delay calculations, to calculate stops for congestion.

One might also want to simulate the intersections in any of the commercial software that are available in the market and get a measure of average number of stops.

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Appendix A

Data Set

The following pages are one-page details of intersections developed through simulation. This data is referred to in Chapter 4.

Intersection 2

	V1L	189	S1L	1615	G1L		11.61567
	V1R	82	S1R	1300	G1R		29.09639
	V1T	1349	S1T	5550	G1T		11.61567
	V2L	156	S2L	1615	G2L		13.1835
	V2R	149	S2R	1615	G2R		29.09639
	V2T	1194	S2T	3700	G2T		13.1835
	V3L	237	S3L	1300	G3L		11.61567
	V3R	250	S3R	1615	G3R		29.09639
	V3T	2307	S3T	5550	G3T		11.61567
	V4L	249	S4L	1615	G4L		13.1835
	V4R	157	S4R	1300	G4R		29.09639
	V4T	1437	S4T	5550	G4T		13.1835
Output 1		7756					
	N1L	1		1		189	
	N1R	0		0		0	
	N1T	3		1		1431	
	N2L	1		1		156	
	N2R	1		1		149	
	N2T	2		1		1194	
	N3L	0		0		0	
	N3R	1		1		250	
	N3T	3		1		2544	
	N4L	1		1		249	
	N4R	0		0		0	
	N4T	3		1		1594	
Input 1 (N)		2.179345				7756	
	Phase No	1					
	y1	0					
	y2	0					
	y3	0					
	y4	0					
	P	2					
Input 2 (PC)	PC	0.443477					
	C	24.79917					
Assume a lost time per phase to be 3.5 sec							
	L	9					
	Gte	15.79917					
	CCC	4.297217					
Input 3 (TC)	TC	3.082259	13.66732				
Output 2 (VD)	Delay	22541.76			d1L'	4.374404	d1T'

Intersection 3

	V1L	124	S1L	1300	G1L	48.75286
	V1R	219	S1R	1300	G1R	90.2467
	V1T	1178	S1T	3400	G1T	48.75286
	V2L	200	S2L	1615	G2L	43.31101
	V2R	198	S2R	1615	G2R	90.2467
	V2T	2227	S2T	3700	G2T	43.31101
	V3L	175	S3L	1615	G3L	48.75286
	V3R	243	S3R	1615	G3R	90.2467
	V3T	1842	S3T	5550	G3T	48.75286
	V4L	174	S4L	1615	G4L	43.31101
	V4R	168	S4R	1300	G4R	90.2467
	V4T	506	S4T	1850	G4T	43.31101
Output 1		7254				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1521	
	N2L	1	1		200	
	N2R	1	1		198	
	N2T	2	1		2227	
	N3L	1	1		175	
	N3R	1	1		243	
	N3T	3	1		1842	
	N4L	1	1		174	
	N4R	0	0		0	
	N4T	1	1		674	
Input 1 (N)		2.024676			7254	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.320575				
	C	92.06387				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	83.06387				
	CCC	1.81717				
Input 3 (TC)	TC	3.114144	51.1583			
Output 2 (VD)	Delay	114576.1				
15.79488	B					

Intersection 5

	V1L	83	S1L	1300	G1L	9.546702
	V1R	230	S1R	1615	G1R	48.12093
	V1T	333	S1T	3700	G1T	9.546702
	V2L	171	S2L	1615	G2L	6.873821
	V2R	172	S2R	1615	G2R	48.12093
	V2T	1113	S2T	3700	G2T	29.08139
	V3L	201	S3L	1300	G3L	9.546702
	V3R	185	S3R	1615	G3R	48.12093
	V3T	692	S3T	1850	G3T	9.546702
	V4L	75	S4L	1615	G4L	6.873821
	V4R	236	S4R	1300	G4R	48.12093
	V4T	460	S4T	1850	G4T	29.08139
Output 1		3951				
	N1L	0	0		0	
	N1R	1	1		230	
	N1T	2	1		416	
	N2L	1	1		171	
	N2R	1	1		172	
	N2T	2	1		1113	
	N3L	0	0		0	
	N3R	1	1		185	
	N3T	1	1		893	
	N4L	1	1		75	
	N4R	0	0		0	
	N4T	1	1		696	
Input 1 (N)		1.387244			3951	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.043184				
	C	45.50191				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	33.00191				
	CCC	2.619017				
Input 3 (TC)	TC	1.627919	25.19265			
Output 2 (VD)	Delay	28237.11				
7.146827	A					

Intersection 6

	V1L	185	S1L	1615	G1L	84.59577
	V1R	302	S1R	1615	G1R	231.3118
	V1T	1197	S1T	3700	G1T	84.59577
	V2L	208	S2L	1615	G2L	114.0512
	V2R	214	S2R	1615	G2R	231.3118
	V2T	2	S2T	1850	G2T	147.553
	V3L	276	S3L	1615	G3L	84.59577
	V3R	176	S3R	1300	G3R	231.3118
	V3T	956	S3T	3700	G3T	84.59577
	V4L	210	S4L	1615	G4L	33.92034
	V4R	182	S4R	1615	G4R	231.3118
	V4T	809	S4T	1850	G4T	147.553
Output 1		4717				
	N1L	1	1		185	
	N1R	1	1		302	
	N1T	2	1		1197	
	N2L	1	1		208	
	N2R	1	1		214	
	N2T	1	1		2	
	N3L	1	1		276	
	N3R	0	0		0	
	N3T	2	1		1132	
	N4L	1	1		210	
	N4R	1	1		182	
	N4T	1	1		809	
Input 1 (N)		1.493958			4717	
	Phase No	6				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.058574				
	C	232.1488				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	219.6488				
	CCC	0.837026				
Input 3 (TC)	TC	2.551493	121.6475			
Output 2 (VD)	Delay	189453.7				
40.16402	D					

Intersection 7

	V1L	209	S1L	1300	G1L	62.78412
	V1R	233	S1R	1300	G1R	116.4762
	V1T	1299	S1T	3400	G1T	62.78412
	V2L	214	S2L	1300	G2L	43.16296
	V2R	192	S2R	1300	G2R	116.4762
	V2T	639	S2T	5100	G2T	43.16296
	V3L	163	S3L	1300	G3L	62.78412
	V3R	286	S3R	1615	G3R	116.4762
	V3T	1896	S3T	5550	G3T	62.78412
	V4L	195	S4L	1300	G4L	43.16296
	V4R	256	S4R	1300	G4R	116.4762
	V4T	788	S4T	3400	G4T	43.16296
Output 1		6370				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1741	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	3	1		1045	
	N3L	0	0		0	
	N3R	1	1		286	
	N3T	3	1		2059	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	2	1		1239	
Input 1 (N)		2.248195			6370	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.31293				
	C	105.9471				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	96.94708				
	CCC	10.52911				
Input 3 (TC)	TC	3.151805	65.27953			
Output 2 (VD)	Delay	69859.74				
10.96699	B					

Intersection 8

	V1L	246	S1L	1615	G1L	8.462826
	V1R	89	S1R	1615	G1R	25.58097
	V1T	432	S1T	5550	G1T	8.462826
	V2L	196	S2L	1300	G2L	7.731941
	V2R	222	S2R	1615	G2R	25.58097
	V2T	1686	S2T	5550	G2T	7.731941
	V3L	252	S3L	1615	G3L	8.462826
	V3R	176	S3R	1615	G3R	25.58097
	V3T	728	S3T	1850	G3T	8.462826
	V4L	190	S4L	1300	G4L	7.731941
	V4R	231	S4R	1615	G4R	25.58097
	V4T	626	S4T	1850	G4T	7.731941
Output 1		5074				
	N1L	1	1		246	
	N1R	1	1		89	
	N1T	3	1		432	
	N2L	0	0		0	
	N2R	1	1		222	
	N2T	3	1		1882	
	N3L	1	1		252	
	N3R	1	1		176	
	N3T	1	1		728	
	N4L	0	0		0	
	N4R	1	1		231	
	N4T	1	1		816	
Input 1 (N)		1.912298			5074	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.153832				
	C	24.65759				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	12.15759				
Input 3 (TC)	TC	1.80607	10.49651			
Output 2 (VD)	Delay	39286.97				
7.742801	A					

Intersection 9

	V1L	269	S1L	1300	G1L	53.20475
	V1R	256	S1R	1300	G1R	80.93068
	V1T	1122	S1T	3400	G1T	53.20475
	V2L	202	S2L	1615	G2L	18.07569
	V2R	166	S2R	1615	G2R	80.93068
	V2T	1123	S2T	1850	G2T	18.07569
	V3L	148	S3L	1615	G3L	53.20475
	V3R	158	S3R	1615	G3R	80.93068
	V3T	674	S3T	1850	G3T	53.20475
	V4L	237	S4L	1615	G4L	18.07569
	V4R	17	S4R	1615	G4R	80.93068
	V4T	724	S4T	3700	G4T	18.07569
Output 1		5096				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1647	
	N2L	1	1		202	
	N2R	1	1		166	
	N2T	1	1		1123	
	N3L	1	1		148	
	N3R	1	1		158	
	N3T	1	1		674	
	N4L	1	1		237	
	N4R	1	1		17	
	N4T	2	1		724	
Input 1 (N)		1.323587			5096	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.120612				
	C	89.35613				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	76.85613				
Input 3 (TC)	TC	2.34416	40.69442			
Output 2 (VD)	Delay	127471.8				
25.01408	C					

Intersection 10

	V1L	153	S1L	1300	G1L	29.86221
	V1R	197	S1R	1615	G1R	77.07985
	V1T	578	S1T	1850	G1T	29.86221
	V2L	214	S2L	1615	G2L	46.56848
	V2R	299	S2R	1300	G2R	77.07985
	V2T	549	S2T	1850	G2T	46.56848
	V3L	105	S3L	1300	G3L	29.86221
	V3R	168	S3R	1615	G3R	77.07985
	V3T	1997	S3T	5550	G3T	29.86221
	V4L	233	S4L	1300	G4L	46.56848
	V4R	217	S4R	1615	G4R	77.07985
	V4T	1338	S4T	5550	G4T	46.56848
Output 1		6048				
	N1L	0	0		0	
	N1R	1	1		197	
	N1T	1	1		731	
	N2L	1	1		214	
	N2R	0	0		0	
	N2T	1	1		848	
	N3L	0	0		0	
	N3R	1	1		168	
	N3T	3	1		2102	
	N4L	0	0		0	
	N4R	1	1		217	
	N4T	3	1		1571	
Input 1 (N)		1.695602			6048	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.271				
	C	76.43068				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	67.43068				
Input 3 (TC)	TC	3.145668	43.18747			
Output 2 (VD)	Delay	64745.16				
10.70522	B					

Intersection 11

	V1L	172	S1L	1300	G1L	681.6896
	V1R	160	S1R	1300	G1R	1276.366
	V1T	1473	S1T	3400	G1T	681.6896
	V2L	173	S2L	1300	G2L	586.3137
	V2R	238	S2R	1300	G2R	1276.366
	V2T	366	S2T	1700	G2T	586.3137
	V3L	153	S3L	1300	G3L	681.6896
	V3R	152	S3R	1300	G3R	1276.366
	V3T	2010	S3T	5100	G3T	681.6896
	V4L	173	S4L	1300	G4L	586.3137
	V4R	183	S4R	1615	G4R	1276.366
	V4T	1219	S4T	3700	G4T	586.3137
Output 1		6472				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1805	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	1	1		777	
	N3L	0	0		0	
	N3R	0	0		0	
	N3T	3	1		2315	
	N4L	0	0		0	
	N4R	1	1		183	
	N4T	2	1		1392	
Input 1 (N)		1.994592			6472	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.293505				
	C	1268.003				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	1259.003				
Input 3 (TC)	TC	3.113257	720.5844			
Output 2 (VD)	Delay	1194415				
184.5512	F					

Intersection 12

	V1L	251	S1L	1300	G1L	15.19219
	V1R	191	S1R	1615	G1R	51.93268
	V1T	996	S1T	5550	G1T	15.19219
	V2L	95	S2L	1300	G2L	41.43167
	V2R	218	S2R	1300	G2R	51.93268
	V2T	1098	S2T	3400	G2T	41.43167
	V3L	162	S3L	1300	G3L	15.19219
	V3R	129	S3R	1615	G3R	51.93268
	V3T	969	S3T	3700	G3T	15.19219
	V4L	195	S4L	1615	G4L	41.43167
	V4R	261	S4R	1300	G4R	51.93268
	V4T	693	S4T	1850	G4T	41.43167
Output 1		5258				
	N1L	0	0		0	
	N1R	1	1		191	
	N1T	3	1		1247	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	2	1		1411	
	N3L	0	0		0	
	N3R	1	1		129	
	N3T	2	1		1131	
	N4L	1	1		195	
	N4R	0	0		0	
	N4T	1	1		954	
Input 1 (N)		1.957969			5258	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.237679				
	C	56.62386				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	47.62386				
Input 3 (TC)	TC	3.151959	31.16024			
Output 2 (VD)	Delay	77974.74				
14.82973	B					

Intersection 13

	V1L	181	S1L	1615	G1L	35.57476
	V1R	166	S1R	1300	G1R	46.69585
	V1T	1885	S1T	5550	G1T	35.57476
	V2L	264	S2L	1615	G2L	10.03236
	V2R	236	S2R	1615	G2R	46.69585
	V2T	345	S2T	1850	G2T	10.03236
	V3L	197	S3L	1615	G3L	35.57476
	V3R	264	S3R	1300	G3R	46.69585
	V3T	685	S3T	1850	G3T	35.57476
	V4L	172	S4L	1300	G4L	10.03236
	V4R	208	S4R	1615	G4R	46.69585
	V4T	886	S4T	1850	G4T	10.03236
Output 1		5489				
	N1L	1	1		181	
	N1R	0	0		0	
	N1T	3	1		2051	
	N2L	1	1		264	
	N2R	1	1		236	
	N2T	1	1		345	
	N3L	1	1		197	
	N3R	0	0		0	
	N3T	1	1		949	
	N4L	0	0		0	
	N4R	1	1		208	
	N4T	1	1		1058	
Input 1 (N)		1.747495			5489	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.27381				
	C	45.60712				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	36.60712				
Input 3 (TC)	TC	3.159228	29.58836			
Output 2 (VD)	Delay	31014.35				
5.650273	A					

Intersection 14

	V1L	230	S1L	1615	G1L	20.1473
	V1R	165	S1R	1300	G1R	31.58282
	V1T	1288	S1T	3700	G1T	20.1473
	V2L	238	S2L	1615	G2L	8.055063
	V2R	67	S2R	1615	G2R	31.58282
	V2T	1491	S2T	3700	G2T	8.055063
	V3L	207	S3L	1300	G3L	20.1473
	V3R	258	S3R	1615	G3R	31.58282
	V3T	1673	S3T	3700	G3T	20.1473
	V4L	308	S4L	1300	G4L	8.055063
	V4R	195	S4R	1615	G4R	31.58282
	V4T	1228	S4T	3700	G4T	8.055063
Output 1		7348				
	N1L	1	1		230	
	N1R	0	0		0	
	N1T	2	1		1453	
	N2L	1	1		238	
	N2R	1	1		67	
	N2T	2	1		1491	
	N3L	0	0		0	
	N3R	1	1		258	
	N3T	2	1		1880	
	N4L	0	0		0	
	N4R	1	1		195	
	N4T	2	1		1536	
Input 1 (N)		1.656777			7348	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.487117				
	C	28.20236				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	19.20236				
	CCC	3.380464				
Input 3 (TC)	TC	3.093223	15.8403			
Output 2 (VD)	Delay	28070.73				
3.820186	A					

Intersection 15

	V1L	188	S1L	1300	G1L	90.16202
	V1R	169	S1R	1615	G1R	109.2484
	V1T	2201	S1T	5550	G1T	90.16202
	V2L	108	S2L	1615	G2L	12.71572
	V2R	143	S2R	1615	G2R	109.2484
	V2T	1387	S2T	5550	G2T	15.40667
	V3L	172	S3L	1300	G3L	90.16202
	V3R	201	S3R	1300	G3R	109.2484
	V3T	752	S3T	1700	G3T	90.16202
	V4L	119	S4L	1615	G4L	12.71572
	V4R	152	S4R	1615	G4R	109.2484
	V4T	2329	S4T	5550	G4T	15.40667
Output 1		7921				
	N1L	0	0		0	
	N1R	1	1		169	
	N1T	3	1		2389	
	N2L	1	1		108	
	N2R	1	1		143	
	N2T	3	1		1387	
	N3L	0	0		0	
	N3R	0	0		0	
	N3T	1	1		1125	
	N4L	1	1		119	
	N4R	1	1		152	
	N4T	3	1		2329	
Input 1 (N)		1.953794			7921	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.180538				
	C	118.2844				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	105.7844				
Input 3 (TC)	TC	3.025711	54.47477			
Output 2 (VD)	Delay	255823				
32.2968	C					

Intersection 16

	V1L	168	S1L	1615	G1L	14.75483
	V1R	244	S1R	1300	G1R	41.47893
	V1T	816	S1T	3700	G1T	14.75483
	V2L	181	S2L	1300	G2L	18.90977
	V2R	195	S2R	1300	G2R	41.47893
	V2T	920	S2T	3400	G2T	18.90977
	V3L	199	S3L	1300	G3L	14.75483
	V3R	171	S3R	1615	G3R	41.47893
	V3T	2434	S3T	5550	G3T	14.75483
	V4L	255	S4L	1300	G4L	18.90977
	V4R	230	S4R	1615	G4R	41.47893
	V4T	1353	S4T	3700	G4T	18.90977
Output 1		7166				
	N1L	1	1		168	
	N1R	0	0		0	
	N1T	2	1		1060	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	2	1		1296	
	N3L	0	0		0	
	N3R	1	1		171	
	N3T	3	1		2633	
	N4L	0	0		0	
	N4R	1	1		230	
	N4T	2	1		1608	
Input 1 (N)		2.063913			7166	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.364857				
	C	33.6646				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	24.6646				
Input 3 (TC)	TC	3.11722	19.45815			
Output 2 (VD)	Delay	28662.89				
3.999845	A					

Intersection 17

	V1L	269	S1L	1300	G1L	24.2594
	V1R	220	S1R	1615	G1R	43.73283
	V1T	1215	S1T	3700	G1T	24.2594
	V2L	225	S2L	1615	G2L	11.03898
	V2R	220	S2R	1615	G2R	43.73283
	V2T	1697	S2T	3700	G2T	11.03898
	V3L	301	S3L	1300	G3L	24.2594
	V3R	204	S3R	1615	G3R	43.73283
	V3T	291	S3T	1850	G3T	24.2594
	V4L	237	S4L	1615	G4L	11.03898
	V4R	185	S4R	1615	G4R	43.73283
	V4T	440	S4T	1850	G4T	11.03898
Output 1		5504				
	N1L	0	0		0	
	N1R	1	1		220	
	N1T	2	1		1484	
	N2L	1	1		225	
	N2R	1	1		220	
	N2T	2	1		1697	
	N3L	0	0		0	
	N3R	1	1		204	
	N3T	1	1		592	
	N4L	1	1		237	
	N4R	1	1		185	
	N4T	1	1		440	
Input 1 (N)		1.578125			5504	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.154165				
	C	46.33736				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	33.83736				
Input 3 (TC)	TC	2.337877	20.94973			
Output 2 (VD)	Delay	59372.68				
10.78719	B					

Intersection 18

	V1L	286	S1L	1300	G1L	69.98385
	V1R	263	S1R	1300	G1R	142.4368
	V1T	777	S1T	3400	G1T	69.98385
	V2L	205	S2L	1300	G2L	63.45005
	V2R	157	S2R	1615	G2R	142.4368
	V2T	2339	S2T	5550	G2T	63.45005
	V3L	183	S3L	1615	G3L	69.98385
	V3R	237	S3R	1300	G3R	142.4368
	V3T	1359	S3T	3700	G3T	69.98385
	V4L	249	S4L	1615	G4L	63.45005
	V4R	231	S4R	1300	G4R	142.4368
	V4T	497	S4T	1850	G4T	63.45005
Output 1		6783				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1326	
	N2L	0	0		0	
	N2R	1	1		157	
	N2T	3	1		2544	
	N3L	1	1		183	
	N3R	0	0		0	
	N3T	2	1		1596	
	N4L	1	1		249	
	N4R	0	0		0	
	N4T	1	1		728	
Input 1 (N)		2.181041			6783	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.421931				
	C	133.4339				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	124.4339				
Input 3 (TC)	TC	3.130916	76.29993			
Output 2 (VD)	Delay	126761.1				
18.68806	B					

Intersection 19

	V1L	160	S1L	1615	G1L	41.84359
	V1R	247	S1R	1615	G1R	331.8821
	V1T	1122	S1T	3700	G1T	107.3023
	V2L	291	S2L	1615	G2L	174.4375
	V2R	302	S2R	1300	G2R	331.8821
	V2T	551	S2T	1850	G2T	174.4375
	V3L	204	S3L	1615	G3L	41.84359
	V3R	189	S3R	1615	G3R	331.8821
	V3T	2048	S3T	3700	G3T	107.3023
	V4L	175	S4L	1300	G4L	174.4375
	V4R	249	S4R	1300	G4R	331.8821
	V4T	371	S4T	1700	G4T	174.4375
Output 1		5909				
	N1L	1	1		160	
	N1R	1	1		247	
	N1T	2	1		1122	
	N2L	1	1		291	
	N2R	0	0		0	
	N2T	1	1		853	
	N3L	1	1		204	
	N3R	1	1		189	
	N3T	2	1		2048	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	1	1		795	
Input 1 (N)		1.536639			5909	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.070967				
	C	323.5834				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	311.0834				
Input 3 (TC)	TC	2.275162	156.5521			
Output 2 (VD)	Delay	520905.5				
88.1546	F					

Intersection 20

	V1L	177	S1L	1615	G1L	50.67968
	V1R	207	S1R	1300	G1R	431.9463
	V1T	892	S1T	3700	G1T	176.3133
	V2L	142	S2L	1615	G2L	186.9745
	V2R	245	S2R	1300	G2R	431.9463
	V2T	1203	S2T	3700	G2T	186.9745
	V3L	202	S3L	1615	G3L	50.67968
	V3R	197	S3R	1300	G3R	431.9463
	V3T	1171	S3T	3700	G3T	176.3133
	V4L	196	S4L	1615	G4L	186.9745
	V4R	179	S4R	1615	G4R	431.9463
	V4T	1022	S4T	3700	G4T	186.9745
Output 1		5833				
	N1L	1	1		177	
	N1R	0	0		0	
	N1T	2	1		1099	
	N2L	1	1		142	
	N2R	0	0		0	
	N2T	2	1		1448	
	N3L	1	1		202	
	N3R	0	0		0	
	N3T	2	1		1368	
	N4L	1	1		196	
	N4R	1	1		179	
	N4T	2	1		1022	
Input 1 (N)		1.671524			5833	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.132261				
	C	413.9675				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	401.4675				
Input 3 (TC)	TC	2.04528	209.1221			
Output 2 (VD)	Delay	717099.1				
122.9383	F					

Intersection 21

	V1L	246	S1L	1615	G1L	23.00877
	V1R	195	S1R	1615	G1R	46.86068
	V1T	589	S1T	1850	G1T	23.00877
	V2L	261	S2L	1615	G2L	11.07733
	V2R	145	S2R	1615	G2R	46.86068
	V2T	347	S2T	1850	G2T	11.07733
	V3L	269	S3L	1300	G3L	23.00877
	V3R	190	S3R	1615	G3R	46.86068
	V3T	1612	S3T	5550	G3T	23.00877
	V4L	234	S4L	1615	G4L	11.07733
	V4R	207	S4R	1615	G4R	46.86068
	V4T	783	S4T	1850	G4T	11.07733
Output 1		5078				
	N1L	1	1		246	
	N1R	1	1		195	
	N1T	1	1		589	
	N2L	1	1		261	
	N2R	1	1		145	
	N2T	1	1		347	
	N3L	0	0		0	
	N3R	1	1		190	
	N3T	3	1		1881	
	N4L	1	1		234	
	N4R	1	1		207	
	N4T	1	1		783	
Input 1 (N)		1.74104			5078	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.192706				
	C	45.16343				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	32.66343				
Input 3 (TC)	TC	2.164047	22.65238			
Output 2 (VD)	Delay	38179.13				
7.518538	A					

Intersection 22

	V1L	196	S1L	1615	G1L	42.00598
	V1R	186	S1R	1300	G1R	267.753
	V1T	1937	S1T	3700	G1T	181.2024
	V2L	256	S2L	1615	G2L	46.48219
	V2R	152	S2R	1615	G2R	267.753
	V2T	686	S2T	1850	G2T	46.48219
	V3L	231	S3L	1615	G3L	42.00598
	V3R	198	S3R	1615	G3R	267.753
	V3T	349	S3T	1850	G3T	181.2024
	V4L	176	S4L	1300	G4L	46.48219
	V4R	161	S4R	1615	G4R	267.753
	V4T	1239	S4T	5550	G4T	46.48219
Output 1		5767				
	N1L	1	1		196	
	N1R	0	0		0	
	N1T	2	1		2123	
	N2L	1	1		256	
	N2R	1	1		152	
	N2T	1	1		686	
	N3L	1	1		231	
	N3R	1	1		198	
	N3T	1	1		349	
	N4L	0	0		0	
	N4R	1	1		161	
	N4T	3	1		1415	
Input 1 (N)		1.368649			5767	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.152056				
	C	269.6906				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	257.1906				
Input 3 (TC)	TC	1.550546	126.2958			
Output 2 (VD)	Delay	397622.9				
68.94797	E					

Intersection 23

	V1L	254	S1L	1615	G1L	12.53698
	V1R	197	S1R	1300	G1R	47.99235
	V1T	750	S1T	3700	G1T	21.39455
	V2L	171	S2L	1300	G2L	17.20493
	V2R	165	S2R	1615	G2R	47.99235
	V2T	1430	S2T	3700	G2T	17.20493
	V3L	152	S3L	1615	G3L	12.53698
	V3R	235	S3R	1615	G3R	47.99235
	V3T	1706	S3T	3700	G3T	21.39455
	V4L	193	S4L	1615	G4L	17.20493
	V4R	239	S4R	1300	G4R	47.99235
	V4T	513	S4T	3700	G4T	17.20493
Output 1		6005				
	N1L	1	1		254	
	N1R	0	0		0	
	N1T	2	1		947	
	N2L	0	0		0	
	N2R	1	1		165	
	N2T	2	1		1601	
	N3L	1	1		152	
	N3R	1	1		235	
	N3T	2	1		1706	
	N4L	1	1		193	
	N4R	0	0		0	
	N4T	2	1		752	
Input 1 (N)		1.708743			6005	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.126289				
	C	51.13645				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	38.63645				
Input 3 (TC)	TC	1.81212	22.88899			
Output 2 (VD)	Delay	91801.58				
15.28752	B					

Intersection 24

	V1L	218	S1L	1615	G1L	49.22057
	V1R	227	S1R	1615	G1R	76.44103
	V1T	2679	S1T	5550	G1T	49.22057
	V2L	171	S2L	1615	G2L	10.3142
	V2R	128	S2R	1615	G2R	76.44103
	V2T	1736	S2T	5550	G2T	16.17899
	V3L	228	S3L	1615	G3L	49.22057
	V3R	210	S3R	1300	G3R	76.44103
	V3T	1416	S3T	5550	G3T	49.22057
	V4L	128	S4L	1615	G4L	10.3142
	V4R	266	S4R	1615	G4R	76.44103
	V4T	2158	S4T	5550	G4T	16.17899
Output 1		9565				
	N1L	1	1		218	
	N1R	1	1		227	
	N1T	3	1		2679	
	N2L	1	1		171	
	N2R	1	1		128	
	N2T	3	1		1736	
	N3L	1	1		228	
	N3R	0	0		0	
	N3T	3	1		1626	
	N4L	1	1		128	
	N4R	1	1		266	
	N4T	3	1		2158	
Input 1 (N)		2.263461			9565	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.319271				
	C	75.71376				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	63.21376				
Input 3 (TC)	TC	2.41091	36.91773			
Output 2 (VD)	Delay	143768.4				
15.03067	B					

Intersection 25

	V1L	223	S1L	1300	G1L	158.4935
	V1R	177	S1R	1615	G1R	302.9711
	V1T	2743	S1T	5550	G1T	158.4935
	V2L	209	S2L	1615	G2L	137.5763
	V2R	275	S2R	1615	G2R	302.9711
	V2T	2941	S2T	5550	G2T	137.5763
	V3L	180	S3L	1300	G3L	158.4935
	V3R	92	S3R	1615	G3R	302.9711
	V3T	964	S3T	3700	G3T	158.4935
	V4L	211	S4L	1615	G4L	137.5763
	V4R	252	S4R	1300	G4R	302.9711
	V4T	2004	S4T	5550	G4T	137.5763
Output 1		10271				
	N1L	0	0		0	
	N1R	1	1		177	
	N1T	3	1		2966	
	N2L	1	1		209	
	N2R	1	1		275	
	N2T	3	1		2941	
	N3L	0	0		0	
	N3R	1	1		92	
	N3T	2	1		1144	
	N4L	1	1		211	
	N4R	0	0		0	
	N4T	3	1		2256	
Input 1 (N)		2.261902			10271	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.606979				
	C	296.0698				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	287.0698				
Input 3 (TC)	TC	3.0775	158.7645			
Output 2 (VD)	Delay	556778.9				
54.20883	D					

Intersection 26

	V1L	141	S1L	1615	G1L	11.23545
	V1R	64	S1R	1615	G1R	83.33161
	V1T	1360	S1T	3700	G1T	36.7959
	V2L	189	S2L	1615	G2L	25.14479
	V2R	163	S2R	1615	G2R	83.33161
	V2T	1350	S2T	3700	G2T	25.14479
	V3L	222	S3L	1615	G3L	11.23545
	V3R	200	S3R	1615	G3R	83.33161
	V3T	1554	S3T	5550	G3T	36.7959
	V4L	98	S4L	1615	G4L	25.14479
	V4R	223	S4R	1300	G4R	83.33161
	V4T	689	S4T	3700	G4T	25.14479
Output 1		6253				
	N1L	1	1		141	
	N1R	1	1		64	
	N1T	2	1		1360	
	N2L	1	1		189	
	N2R	1	1		163	
	N2T	2	1		1350	
	N3L	1	1		222	
	N3R	1	1		200	
	N3T	3	1		1554	
	N4L	1	1		98	
	N4R	0	0		0	
	N4T	2	1		912	
Input 1 (N)		1.930753			6253	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.091153				
	C	73.17614				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	60.67614				
Input 3 (TC)	TC	1.79119	35.81546			
Output 2 (VD)	Delay	97993.14				
15.67138	B					

Intersection 27

	V1L	163	S1L	1615	G1L	78.51156
	V1R	174	S1R	1615	G1R	142.8732
	V1T	909	S1T	1850	G1T	78.51156
	V2L	197	S2L	1300	G2L	60.68165
	V2R	131	S2R	1300	G2R	142.8732
	V2T	1008	S2T	3400	G2T	60.68165
	V3L	269	S3L	1615	G3L	78.51156
	V3R	172	S3R	1300	G3R	142.8732
	V3T	1500	S3T	5550	G3T	78.51156
	V4L	257	S4L	1300	G4L	60.68165
	V4R	182	S4R	1615	G4R	142.8732
	V4T	1086	S4T	3700	G4T	60.68165
Output 1		6048				
	N1L	1	1		163	
	N1R	1	1		174	
	N1T	1	1		909	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	2	1		1336	
	N3L	1	1		269	
	N3R	0	0		0	
	N3T	3	1		1672	
	N4L	0	0		0	
	N4R	1	1		182	
	N4T	2	1		1343	
Input 1 (N)		1.77414			6048	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.334034				
		0.322759				
	C	139.1932				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	130.1932				
Input 3 (TC)	TC	3.108962	78.01283			
Output 2 (VD)	Delay	112373.5				
18.58028	B					

Intersection 28

	V1L	188	S1L	1615	G1L	33.27868
	V1R	161	S1R	1615	G1R	159.1469
	V1T	318	S1T	1850	G1T	56.82221
	V2L	185	S2L	1615	G2L	35.0145
	V2R	176	S2R	1615	G2R	159.1469
	V2T	1611	S2T	5550	G2T	62.99691
	V3L	225	S3L	1615	G3L	33.27868
	V3R	183	S3R	1300	G3R	159.1469
	V3T	719	S3T	3700	G3T	56.82221
	V4L	240	S4L	1615	G4L	35.0145
	V4R	161	S4R	1300	G4R	159.1469
	V4T	108	S4T	1850	G4T	62.99691
Output 1		4275				
	N1L	1	1		188	
	N1R	1	1		161	
	N1T	1	1		318	
	N2L	1	1		185	
	N2R	1	1		176	
	N2T	3	1		1611	
	N3L	1	1		225	
	N3R	0	0		0	
	N3T	2	1		902	
	N4L	1	1		240	
	N4R	0	0		0	
	N4T	1	1		269	
Input 1 (N)		1.964912			4275	
	Phase No	2				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	4				
Input 2 (PC)	PC	0				
	C	188.1123				
Assume a lost time per phase to be 3.5 sec						
	L	16				
	Gte	172.1123				
Input 3 (TC)	TC	1.243203	71.16271			
Output 2 (VD)	Delay	223758.5				
52.34117	D					

Intersection 29

	V1L	233	S1L	1615	G1L	63.4103
	V1R	225	S1R	1615	G1R	168.3459
	V1T	1297	S1T	3700	G1T	131.9226
	V2L	251	S2L	1615	G2L	26.21933
	V2R	146	S2R	1300	G2R	168.3459
	V2T	694	S2T	5550	G2T	26.21933
	V3L	217	S3L	1615	G3L	63.4103
	V3R	228	S3R	1615	G3R	168.3459
	V3T	335	S3T	1850	G3T	131.9226
	V4L	212	S4L	1615	G4L	26.21933
	V4R	188	S4R	1615	G4R	168.3459
	V4T	1253	S4T	5550	G4T	26.21933
Output 1		5279				
	N1L	1	1		233	
	N1R	1	1		225	
	N1T	2	1		1297	
	N2L	1	1		251	
	N2R	0	0		0	
	N2T	3	1		840	
	N3L	1	1		217	
	N3R	1	1		228	
	N3T	1	1		335	
	N4L	1	1		212	
	N4R	1	1		188	
	N4T	3	1		1253	
Input 1 (N)		1.564501			5279	
	Phase No	5				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.124828				
	C	158.1419				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	145.6419				
Input 3 (TC)	TC	2.425734	83.25614			
Output 2 (VD)	Delay	147393.4				
27.9207	C					

Intersection 30

	V1L	250	S1L	1615	G1L	188.9731
	V1R	261	S1R	1300	G1R	359.5315
	V1T	353	S1T	1850	G1T	188.9731
	V2L	120	S2L	1615	G2L	168.1099
	V2R	140	S2R	1300	G2R	359.5315
	V2T	1371	S2T	3700	G2T	168.1099
	V3L	202	S3L	1615	G3L	188.9731
	V3R	252	S3R	1300	G3R	359.5315
	V3T	1471	S3T	3700	G3T	188.9731
	V4L	213	S4L	1300	G4L	168.1099
	V4R	250	S4R	1300	G4R	359.5315
	V4T	304	S4T	1700	G4T	168.1099
Output 1		5187				
	N1L	1	1		250	
	N1R	0	0		0	
	N1T	1	1		614	
	N2L	1	1		120	
	N2R	0	0		0	
	N2T	2	1		1511	
	N3L	1	1		202	
	N3R	0	0		0	
	N3T	2	1		1723	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	1	1		767	
Input 1 (N)		1.623675			5187	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.266514				
	C	357.083				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	348.083				
Input 3 (TC)	TC	3.174089	210.5888			
Output 2 (VD)	Delay	247059.3				
47.63048	D					

Intersection 31

	V1L	150	S1L	1300	G1L	23.50866
	V1R	273	S1R	1300	G1R	32.41711
	V1T	964	S1T	3400	G1T	23.50866
	V2L	160	S2L	1615	G2L	4.243159
	V2R	184	S2R	1615	G2R	32.41711
	V2T	1454	S2T	3700	G2T	4.243159
	V3L	176	S3L	1615	G3L	23.50866
	V3R	97	S3R	1300	G3R	32.41711
	V3T	1599	S3T	3700	G3T	23.50866
	V4L	132	S4L	1615	G4L	4.243159
	V4R	205	S4R	1615	G4R	32.41711
	V4T	1471	S4T	3700	G4T	4.243159
Output 1		6865				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1387	
	N2L	1	1		160	
	N2R	1	1		184	
	N2T	2	1		1454	
	N3L	1	1		176	
	N3R	0	0		0	
	N3T	2	1		1696	
	N4L	1	1		132	
	N4R	1	1		205	
	N4T	2	1		1471	
Input 1 (N)		1.66118			6865	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.290556				
	C	27.75182				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	18.75182				
Input 3 (TC)	TC	3.351123	15.4656			
Output 2 (VD)	Delay	32532.46				
4.738887	A					

Intersection 32

	V1L	154	S1L	1300	G1L	64.47428
	V1R	252	S1R	1300	G1R	108.9286
	V1T	1383	S1T	3400	G1T	64.47428
	V2L	115	S2L	1615	G2L	12.34776
	V2R	264	S2R	1615	G2R	108.9286
	V2T	734	S2T	1850	G2T	18.14389
	V3L	192	S3L	1615	G3L	64.47428
	V3R	234	S3R	1300	G3R	108.9286
	V3T	633	S3T	1850	G3T	64.47428
	V4L	209	S4L	1615	G4L	12.34776
	V4R	222	S4R	1300	G4R	108.9286
	V4T	368	S4T	3700	G4T	18.14389
Output 1		4760				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1789	
	N2L	1	1		115	
	N2R	1	1		264	
	N2T	1	1		734	
	N3L	1	1		192	
	N3R	0	0		0	
	N3T	1	1		867	
	N4L	1	1		209	
	N4R	0	0		0	
	N4T	2	1		590	
Input 1 (N)		1.376261			4760	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.126048				
	C	94.96594				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	82.46594				
Input 3 (TC)	TC	2.562042	59.27774			
Output 2 (VD)	Delay	58284.26				
12.24459	B					

Intersection 33

	V1L	258	S1L	1615	G1L	84.81556
	V1R	231	S1R	1300	G1R	503.0577
	V1T	949	S1T	3700	G1T	182.993
	V2L	177	S2L	1615	G2L	238.4916
	V2R	208	S2R	1300	G2R	503.0577
	V2T	562	S2T	1850	G2T	238.4916
	V3L	153	S3L	1615	G3L	84.81556
	V3R	309	S3R	1615	G3R	503.0577
	V3T	1990	S3T	5550	G3T	182.993
	V4L	214	S4L	1615	G4L	238.4916
	V4R	212	S4R	1300	G4R	503.0577
	V4T	643	S4T	3700	G4T	238.4916
Output 1		5906				
	N1L	1	1		258	
	N1R	0	0		0	
	N1T	2	1		1180	
	N2L	1	1		177	
	N2R	0	0		0	
	N2T	1	1		770	
	N3L	1	1		153	
	N3T	3	1		1990	
	N4L	1	1		214	
	N4R	0	0		0	
	N4T	2	1		855	
Input 1 (N)		1.874026			5906	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.081277				
	C	506.3001				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	493.8001				
Input 3 (TC)	TC	2.104642	243.1838			
Output 2 (VD)	Delay	1022835				
173.1857	F					

Intersection 34

	V1L	159	S1L	1615	G1L	16.20075
	V1R	224	S1R	1615	G1R	132.37
	V1T	950	S1T	3700	G1T	37.16869
	V2L	210	S2L	1300	G2L	68.19476
	V2R	211	S2R	1300	G2R	132.37
	V2T	369	S2T	1700	G2T	68.19476
	V3L	207	S3L	1615	G3L	16.20075
	V3R	199	S3R	1615	G3R	132.37
	V3T	1479	S3T	5550	G3T	37.16869
	V4L	260	S4L	1615	G4L	68.19476
	V4R	188	S4R	1300	G4R	132.37
	V4T	1439	S4T	5550	G4T	68.19476
Output 1		5895				
	N1L	1	1		159	
	N1R	1	1		224	
	N1T	2	1		950	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	1	1		790	
	N3L	1	1		207	
	N3R	1	1		199	
	N3T	3	1		1479	
	N4L	1	1		260	
	N4R	0	0		0	
	N4T	3	1		1627	
Input 1 (N)		1.663444			5895	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.13824				
	C	121.5642				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	109.0642				
Input 3 (TC)	TC	2.261395	61.13113			
Output 2 (VD)	Delay	197443.2				
33.49333	C					

Intersection 35

	V1L	210	S1L	1615	G1L	72.09729
	V1R	173	S1R	1300	G1R	262.3701
	V1T	1064	S1T	5550	G1T	149.1946
	V2L	124	S2L	1615	G2L	103.1755
	V2R	203	S2R	1615	G2R	262.3701
	V2T	498	S2T	1850	G2T	103.1755
	V3L	261	S3L	1615	G3L	72.09729
	V3R	162	S3R	1615	G3R	262.3701
	V3T	978	S3T	3700	G3T	149.1946
	V4L	131	S4L	1615	G4L	103.1755
	V4R	163	S4R	1300	G4R	262.3701
	V4T	1781	S4T	5550	G4T	103.1755
Output 1		5748				
	N1L	1	1		210	
	N1R	0	0		0	
	N1T	3	1		1237	
	N2L	1	1		124	
	N2R	1	1		203	
	N2T	1	1		498	
	N3L	1	1		261	
	N3R	1	1		162	
	N3T	2	1		978	
	N4L	1	1		131	
	N4R	0	0		0	
	N4T	3	1		1944	
Input 1 (N)		1.601079			5748	
	Phase No	5				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.167738				
	C	252.3701				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	239.8701				
Input 3 (TC)	TC	2.510969	136.392			
Output 2 (VD)	Delay	212323.3				
36.93864	D					

Intersection 36

	V1L	210	S1L	1615	G1L	69.22222
	V1R	263	S1R	1300	G1R	115.7482
	V1T	663	S1T	1850	G1T	69.22222
	V2L	230	S2L	1615	G2L	14.26812
	V2R	182	S2R	1615	G2R	115.7482
	V2T	395	S2T	1850	G2T	14.26812
	V3L	239	S3L	1615	G3L	69.22222
	V3R	187	S3R	1300	G3R	115.7482
	V3T	2157	S3T	5550	G3T	69.22222
	V4L	237	S4L	1615	G4L	14.26812
	V4R	169	S4R	1615	G4R	115.7482
	V4T	1255	S4T	3700	G4T	14.26812
Output 1		6187				
	N1L	1	1		210	
	N1R	0	0		0	
	N1T	1	1		926	
	N2L	1	1		230	
	N2R	1	1		182	
	N2T	1	1		395	
	N3L	1	1		239	
	N3R	0	0		0	
	N3T	3	1		2344	
	N4L	1	1		237	
	N4R	1	1		169	
	N4T	2	1		1255	
Input 1 (N)		1.758041			6187	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.212301				
	C	97.75847				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	85.25847				
Input 3 (TC)	TC	2.659437	56.44211			
Output 2 (VD)	Delay	87604.79				
14.15949	B					

Intersection 37

	V1L	144	S1L	1615	G1L	38.98211
	V1R	156	S1R	1300	G1R	78.29179
	V1T	566	S1T	1850	G1T	38.98211
	V2L	280	S2L	1615	G2L	13.47553
	V2R	266	S2R	1615	G2R	78.29179
	V2T	2758	S2T	5550	G2T	13.47553
	V3L	187	S3L	1300	G3L	38.98211
	V3R	114	S3R	1615	G3R	78.29179
	V3T	399	S3T	1850	G3T	38.98211
	V4L	192	S4L	1615	G4L	13.47553
	V4R	170	S4R	1615	G4R	78.29179
	V4T	483	S4T	3700	G4T	13.47553
Output 1		5715				
	N1L	1	1		144	
	N1R	0	0		0	
	N1T	1	1		722	
	N2L	1	1		280	
	N2R	1	1		266	
	N2T	3	1		2758	
	N3L	0	0		0	
	N3R	1	1		114	
	N3T	1	1		586	
	N4L	1	1		192	
	N4R	1	1		170	
	N4T	2	1		483	
Input 1 (N)		1.965529			5715	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.056701				
	C	65.93318				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	53.43318				
Input 3 (TC)	TC	2.862424	27.26675			
Output 2 (VD)	Delay	96771.71				
16.93293	B					

Intersection 38

	V1L	147	S1L	1615	G1L	20.97632
	V1R	156	S1R	1615	G1R	47.13461
	V1T	1471	S1T	5550	G1T	20.97632
	V2L	216	S2L	1300	G2L	32.63585
	V2R	216	S2R	1300	G2R	47.13461
	V2T	1103	S2T	3400	G2T	32.63585
	V3L	309	S3L	1615	G3L	20.97632
	V3R	228	S3R	1615	G3R	47.13461
	V3T	1498	S3T	3700	G3T	20.97632
	V4L	244	S4L	1300	G4L	32.63585
	V4R	112	S4R	1300	G4R	47.13461
	V4T	193	S4T	1700	G4T	32.63585
Output 1		5893				
	N1L	1	1		147	
	N1R	1	1		156	
	N1T	3	1		1471	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	2	1		1535	
	N3L	1	1		309	
	N3R	1	1		228	
	N3T	2	1		1498	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	1	1		549	
Input 1 (N)		2.014085			5893	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.34221				
	C	53.61217				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	44.61217				
Input 3 (TC)	TC	3.120821	27.61112			
Output 2 (VD)	Delay	52740.79				
8.949735	A					

Intersection 39

	V1L	252	S1L	1615	G1L	31.5065
	V1R	213	S1R	1300	G1R	172.6962
	V1T	500	S1T	1850	G1T	113.161
	V2L	166	S2L	1300	G2L	31.5065
	V2R	252	S2R	1615	G2R	172.6962
	V2T	447	S2T	1850	G2T	31.5065
	V3L	179	S3L	1615	G3L	31.5065
	V3R	275	S3R	1300	G3R	172.6962
	V3T	704	S3T	1850	G3T	113.161
	V4L	173	S4L	1300	G4L	31.5065
	V4R	168	S4R	1615	G4R	172.6962
	V4T	3079	S4T	5550	G4T	31.5065
Output 1		6408				
	N1L	1	1		252	
	N1R	0	0		0	
	N1T	1	1		713	
	N2L	0	0		0	
	N2R	1	1		252	
	N2T	1	1		613	
	N3L	1	1		179	
	N3R	0	0		0	
	N3T	1	1		979	
	N4L	0	0		0	
	N4R	1	1		168	
	N4T	3	1		3252	
Input 1 (N)		1.000468			6408	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.204321				
	C	176.174				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	163.674				
Input 3 (TC)	TC	2.102684	66.85486			
Output 2 (VD)	Delay	576139.1				
89.90935	F					

Intersection 40

	V1L	237	S1L	1615	G1L	36.02486
	V1R	195	S1R	1300	G1R	91.16709
	V1T	824	S1T	3700	G1T	36.02486
	V2L	226	S2L	1615	G2L	17.81426
	V2R	161	S2R	1615	G2R	91.16709
	V2T	1460	S2T	3700	G2T	42.91963
	V3L	120	S3L	1300	G3L	36.02486
	V3R	146	S3R	1615	G3R	91.16709
	V3T	1127	S3T	3700	G3T	36.02486
	V4L	189	S4L	1615	G4L	17.81426
	V4R	157	S4R	1300	G4R	91.16709
	V4T	1680	S4T	5550	G4T	42.91963
Output 1		6522				
	N1L	1	1		237	
	N1R	0	0		0	
	N1T	2	1		1019	
	N2L	1	1		226	
	N2R	1	1		161	
	N2T	2	1		1460	
	N3L	0	0		0	
	N3R	1	1		146	
	N3T	2	1		1247	
	N4L	1	1		189	
	N4R	0	0		0	
	N4T	3	1		1837	
Input 1 (N)		1.571757			6522	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.127076				
	C	96.75876				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	84.25876				
Input 3 (TC)	TC	1.845675	43.75729			
Output 2 (VD)	Delay	127046				
19.4796	B					

Intersection 41

	V1L	206	S1L	1615	G1L	109.2862
	V1R	271	S1R	1615	G1R	169.6759
	V1T	1248	S1T	3700	G1T	109.2862
	V2L	241	S2L	1615	G2L	25.33451
	V2R	239	S2R	1615	G2R	169.6759
	V2T	685	S2T	3700	G2T	25.33451
	V3L	264	S3L	1300	G3L	109.2862
	V3R	271	S3R	1300	G3R	169.6759
	V3T	464	S3T	1700	G3T	109.2862
	V4L	179	S4L	1615	G4L	25.33451
	V4R	199	S4R	1615	G4R	169.6759
	V4T	319	S4T	1850	G4T	25.33451
Output 1		4586				
	N1L	1	1		206	
	N1R	1	1		271	
	N1T	2	1		1248	
	N2L	1	1		241	
	N2R	1	1		239	
	N2T	2	1		685	
	N3L	0	0		0	
	N3R	0	0		0	
	N3T	1	1		999	
	N4L	1	1		179	
	N4R	1	1		199	
	N4T	1	1		319	
Input 1 (N)		1.421718			4586	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.147589				
	C	159.9552				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	147.4552				
Input 3 (TC)	TC	2.580154	96.12322			
Output 2 (VD)	Delay	96912.11				
21.13216	C					

Intersection 42

	V1L	121	S1L	1615	G1L	27.64149
	V1R	288	S1R	1615	G1R	52.37025
	V1T	895	S1T	3700	G1T	27.64149
	V2L	115	S2L	1615	G2L	45.17304
	V2R	248	S2R	1300	G2R	52.37025
	V2T	600	S2T	1850	G2T	45.17304
	V3L	153	S3L	1300	G3L	27.64149
	V3R	247	S3R	1615	G3R	52.37025
	V3T	392	S3T	3700	G3T	27.64149
	V4L	279	S4L	1615	G4L	45.17304
	V4R	138	S4R	1300	G4R	52.37025
	V4T	2028	S4T	5550	G4T	45.17304
Output 1		5504				
	N1L	1	1		121	
	N1R	1	1		288	
	N1T	2	1		895	
	N2L	1	1		115	
	N2R	0	0		0	
	N2T	1	1		848	
	N3L	0	0		0	
	N3R	1	1		247	
	N3T	2	1		545	
	N4L	1	1		279	
	N4R	0	0		0	
	N4T	3	1		2166	
Input 1 (N)		1.262173			5504	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.20312				
	C	72.81453				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	63.81453				
Input 3 (TC)	TC	3.167333	41.40521			
Output 2 (VD)	Delay	54669.23				
9.932636	A					

Intersection 43

	V1L	242	S1L	1615	G1L	129.9163
	V1R	197	S1R	1300	G1R	196.3579
	V1T	1087	S1T	3700	G1T	129.9163
	V2L	229	S2L	1615	G2L	28.8653
	V2R	248	S2R	1615	G2R	196.3579
	V2T	1115	S2T	3700	G2T	31.43022
	V3L	236	S3L	1615	G3L	129.9163
	V3R	191	S3R	1300	G3R	196.3579
	V3T	838	S3T	1850	G3T	129.9163
	V4L	162	S4L	1615	G4L	28.8653
	V4R	238	S4R	1615	G4R	196.3579
	V4T	785	S4T	5550	G4T	31.43022
Output 1		5568				
	N1L	1	1		242	
	N1R	0	0		0	
	N1T	2	1		1284	
	N2L	1	1		229	
	N2R	1	1		248	
	N2T	2	1		1115	
	N3L	1	1		236	
	N3R	0	0		0	
	N3T	1	1		1029	
	N4L	1	1		162	
	N4R	1	1		238	
	N4T	3	1		785	
Input 1 (N)		1.431394			5568	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.159489				
	C	190.2118				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	177.7118				
Input 3 (TC)	TC	2.593012	99.64249			
Output 2 (VD)	Delay	190865.9				
34.27908	C					

Intersection 44

	V1L	120	S1L	1615	G1L	31.68548
	V1R	151	S1R	1300	G1R	259.2312
	V1T	1010	S1T	3700	G1T	98.84916
	V2L	210	S2L	1615	G2L	137.7293
	V2R	198	S2R	1300	G2R	259.2312
	V2T	2250	S2T	5550	G2T	137.7293
	V3L	165	S3L	1615	G3L	31.68548
	V3R	173	S3R	1300	G3R	259.2312
	V3T	523	S3T	3700	G3T	98.84916
	V4L	128	S4L	1615	G4L	137.7293
	V4R	236	S4R	1300	G4R	259.2312
	V4T	2020	S4T	5550	G4T	137.7293
Output 1		7184				
	N1L	1	1		120	
	N1R	0	0		0	
	N1T	2	1		1161	
	N2L	1	1		210	
	N2R	0	0		0	
	N2T	3	1		2448	
	N3L	1	1		165	
	N3R	0	0		0	
	N3T	2	1		696	
	N4L	1	1		128	
	N4R	0	0		0	
	N4T	3	1		2256	
Input 1 (N)		1.940423			7184	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.247292				
	C	268.2639				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	255.7639				
Input 3 (TC)	TC	2.132332	138.0456			
Output 2 (VD)	Delay	345667.5				
48.11629	D					

Intersection 46

	V1L	150	S1L	1300	G1L	72.69561
	V1R	142	S1R	1615	G1R	174.1981
	V1T	1266	S1T	3700	G1T	72.69561
	V2L	279	S2L	1615	G2L	113.0502
	V2R	249	S2R	1300	G2R	174.1981
	V2T	1694	S2T	5550	G2T	113.0502
	V3L	180	S3L	1300	G3L	72.69561
	V3R	203	S3R	1615	G3R	174.1981
	V3T	215	S3T	1850	G3T	72.69561
	V4L	242	S4L	1615	G4L	113.0502
	V4R	173	S4R	1300	G4R	174.1981
	V4T	2702	S4T	5550	G4T	113.0502
Output 1		7495				
	N1L	0	0		0	
	N1R	1	1		142	
	N1T	2	1		1416	
	N2L	1	1		279	
	N2R	0	0		0	
	N2T	3	1		1943	
	N3L	0	0		0	
	N3R	1	1		203	
	N3T	1	1		395	
	N4L	1	1		242	
	N4R	0	0		0	
	N4T	3	1		2875	
Input 1 (N)		1.707805			7495	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.494422				
	C	185.7458				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	176.7458				
Input 3 (TC)	TC	3.102335	109.557			
Output 2 (VD)	Delay	189554.3				
25.29077	C					

Intersection 47

	V1L	146	S1L	1300	G1L	69.32887
	V1R	202	S1R	1300	G1R	94.87344
	V1T	941	S1T	3400	G1T	69.32887
	V2L	204	S2L	1615	G2L	23.1701
	V2R	134	S2R	1615	G2R	94.87344
	V2T	2010	S2T	5550	G2T	27.32067
	V3L	250	S3L	1300	G3L	69.32887
	V3R	184	S3R	1300	G3R	94.87344
	V3T	2212	S3T	5100	G3T	69.32887
	V4L	119	S4L	1615	G4L	23.1701
	V4R	261	S4R	1615	G4R	94.87344
	V4T	3021	S4T	5550	G4T	27.32067
Output 1		9684				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		1289	
	N2L	1	1		204	
	N2R	1	1		134	
	N2T	3	1		2010	
	N3L	0	0		0	
	N3R	0	0		0	
	N3T	3	1		2646	
	N4L	1	1		119	
	N4R	1	1		261	
	N4T	3	1		3021	
Input 1 (N)		2.095002			9684	
	Phase No	3				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.19382				
	C	119.8196				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	107.3196				
Input 3 (TC)	TC	2.405755	48.02546			
Output 2 (VD)	Delay	426074.3				
43.99776	D					

Intersection 48

	V1L	220	S1L	1615	G1L	41.30626
	V1R	228	S1R	1615	G1R	323.7052
	V1T	1175	S1T	3700	G1T	113.8413
	V2L	91	S2L	1300	G2L	151.4866
	V2R	224	S2R	1300	G2R	323.7052
	V2T	1234	S2T	3400	G2T	151.4866
	V3L	177	S3L	1615	G3L	41.30626
	V3R	260	S3R	1300	G3R	323.7052
	V3T	1507	S3T	5550	G3T	113.8413
	V4L	266	S4L	1615	G4L	151.4866
	V4R	179	S4R	1615	G4R	323.7052
	V4T	1445	S4T	5550	G4T	151.4866
Output 1		7006				
	N1L	1	1		220	
	N1R	1	1		228	
	N1T	2	1		1175	
	N2L	0	0		0	
	N2R	0	0		0	
	N2T	2	1		1549	
	N3L	1	1		177	
	N3R	0	0		0	
	N3T	3	1		1767	
	N4L	1	1		266	
	N4R	1	1		179	
	N4T	3	1		1445	
Input 1 (N)		1.893663			7006	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.159632				
	C	306.6341				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	294.1341				
Input 3 (TC)	TC	2.115238	152.7342			
Output 2 (VD)	Delay	223580.5				
31.91272	C					

Intersection 49

	V1L	256	S1L	1615	G1L	54.11113
	V1R	160	S1R	1615	G1R	212.4286
	V1T	823	S1T	5550	G1T	54.11113
	V2L	179	S2L	1300	G2L	153.4057
	V2R	184	S2R	1615	G2R	212.4286
	V2T	624	S2T	1850	G2T	153.4057
	V3L	255	S3L	1615	G3L	54.11113
	V3R	121	S3R	1300	G3R	212.4286
	V3T	300	S3T	1850	G3T	54.11113
	V4L	164	S4L	1300	G4L	153.4057
	V4R	259	S4R	1300	G4R	212.4286
	V4T	737	S4T	1700	G4T	153.4057
Output 1		4062				
	N1L	1	1		256	
	N1R	1	1		160	
	N1T	3	1		823	
	N2L	0	0		0	
	N2R	1	1		184	
	N2T	1	1		803	
	N3L	1	1		255	
	N3R	0	0		0	
	N3T	1	1		421	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	1	1		1160	
Input 1 (N)		1.405465			4062	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.180876				
	C	207.5168				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	198.5168				
Input 3 (TC)	TC	3.178237	123.9831			
Output 2 (VD)	Delay	123587.3				
30.42523	C					

Intersection 51

	V1L	176	S1L	1615	G1L	21.3563
	V1R	212	S1R	1615	G1R	79.62504
	V1T	525	S1T	1850	G1T	40.13181
	V2L	163	S2L	1615	G2L	48.60558
	V2R	181	S2R	1615	G2R	79.62504
	V2T	714	S2T	3700	G2T	48.60558
	V3L	149	S3L	1615	G3L	21.3563
	V3R	159	S3R	1615	G3R	79.62504
	V3T	2432	S3T	5550	G3T	40.13181
	V4L	59	S4L	1300	G4L	48.60558
	V4R	180	S4R	1300	G4R	79.62504
	V4T	397	S4T	1700	G4T	48.60558
Output 1		5347				
	N1L	1	1		176	
	N1R	1	1		212	
	N1T	1	1		525	
	N2L	1	1		163	
	N2R	1	1		181	
	N2T	2	1		714	
	N3L	1	1		149	
	N3R	1	1		159	
	N3T	3	1		2432	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	1	1		636	
Input 1 (N)		2.043389			5347	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.037096				
	C	110.0937				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	97.59369				
Input 3 (TC)	TC	2.200506	46.50969			
Output 2 (VD)	Delay	170735.4				
31.93107	C					

Intersection 52

	V1L	206	S1L	1615	G1L	24.0906
	V1R	151	S1R	1300	G1R	133.9333
	V1T	316	S1T	1850	G1T	44.73399
	V2L	188	S2L	1615	G2L	70.71095
	V2R	97	S2R	1300	G2R	133.9333
	V2T	1090	S2T	3700	G2T	70.71095
	V3L	230	S3L	1615	G3L	24.0906
	V3R	176	S3R	1615	G3R	133.9333
	V3T	1785	S3T	5550	G3T	44.73399
	V4L	172	S4L	1300	G4L	70.71095
	V4R	239	S4R	1300	G4R	133.9333
	V4T	1839	S4T	5100	G4T	70.71095
Output 1		6489				
	N1L	1	1		206	
	N1R	0	0		0	
	N1T	1	1		467	
	N2L	1	1		188	
	N2R	0	0		0	
	N2T	2	1		1187	
	N3L	1	1		230	
	N3R	1	1		176	
	N3T	3	1		1785	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	3	1		2250	
Input 1 (N)		1.733549			6489	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.185143				
	C	139.5355				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	127.0355				
Input 3 (TC)	TC	2.115692	65.62732			
Output 2 (VD)	Delay	208870.8				
32.18844	C					

Intersection 53

	V1L	219	S1L	1615	G1L	42.02254
	V1R	210	S1R	1615	G1R	272.7606
	V1T	1864	S1T	5550	G1T	103.6726
	V2L	131	S2L	1615	G2L	133.4664
	V2R	96	S2R	1615	G2R	272.7606
	V2T	2092	S2T	5550	G2T	133.4664
	V3L	134	S3L	1615	G3L	42.02254
	V3R	193	S3R	1615	G3R	272.7606
	V3T	1488	S3T	5550	G3T	103.6726
	V4L	207	S4L	1300	G4L	133.4664
	V4R	248	S4R	1300	G4R	272.7606
	V4T	304	S4T	1700	G4T	133.4664
Output 1		7186				
	N1L	1	1		219	
	N1R	1	1		210	
	N1T	3	1		1864	
	N2L	1	1		131	
	N2R	1	1		96	
	N2T	3	1		2092	
	N3L	1	1		134	
	N3R	1	1		193	
	N3T	3	1		1488	
	N4L	0	0		0	
	N4R	0	0		0	
	N4T	1	1		759	
Input 1 (N)		2.515308			7186	
	Phase No	4				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	3				
Input 2 (PC)	PC	0.16419				
	C	279.1615				
Assume a lost time per phase to be 3.5 sec						
	L	12.5				
	Gte	266.6615				
Input 3 (TC)	TC	2.060147	129.5566			
Output 2 (VD)	Delay	546565.4				
76.05975	E					

Intersection 54

	V1L	245	S1L	1300	G1L	13.81827
	V1R	100	S1R	1300	G1R	31.16768
	V1T	358	S1T	3400	G1T	13.81827
	V2L	187	S2L	1300	G2L	23.99852
	V2R	155	S2R	1615	G2R	31.16768
	V2T	1426	S2T	3700	G2T	23.99852
	V3L	105	S3L	1615	G3L	13.81827
	V3R	204	S3R	1615	G3R	31.16768
	V3T	928	S3T	3700	G3T	13.81827
	V4L	217	S4L	1615	G4L	23.99852
	V4R	184	S4R	1300	G4R	31.16768
	V4T	1201	S4T	3700	G4T	23.99852
Output 1		5310				
	N1L	0	0		0	
	N1R	0	0		0	
	N1T	2	1		703	
	N2L	0	0		0	
	N2R	1	1		155	
	N2T	2	1		1613	
	N3L	1	1		105	
	N3R	1	1		204	
	N3T	2	1		928	
	N4L	1	1		217	
	N4R	0	0		0	
	N4T	2	1		1385	
Input 1 (N)		1.611299			5310	
	Phase No	1				
	y1	0				
	y2	0				
	y3	0				
	y4	0				
	P	2				
Input 2 (PC)	PC	0.277423				
	C	37.8168				
Assume a lost time per phase to be 3.5 sec						
	L	9				
	Gte	28.8168				
Input 3 (TC)	TC	3.121092	21.73014			
Output 2 (VD)	Delay	31618.84				
5.954585	A					

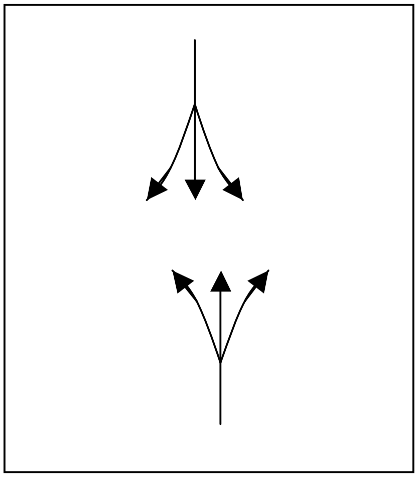
Appendix B

Phasing Plans

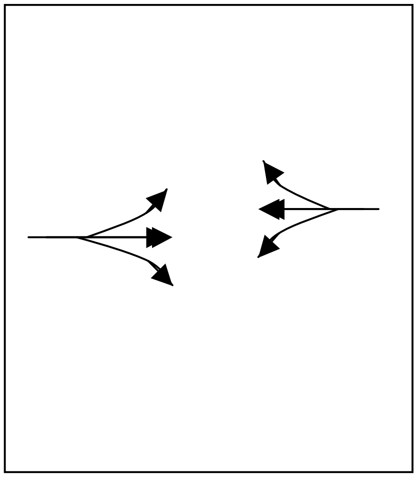
The following six commonly found phasing systems were randomly picked for all the intersections that were created for this study.

Phasing Plan 1:

Phase A



Phase B



Calculating Phasing Coefficients:
No of conflicts=4

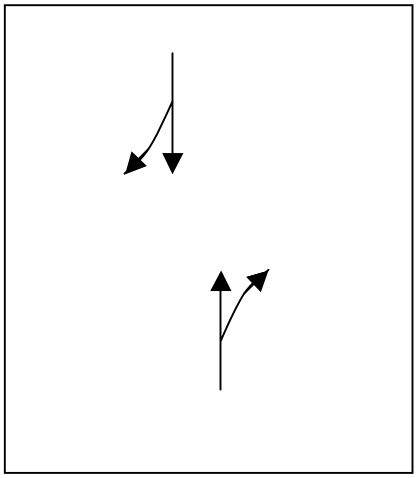
$$\text{Phasing Coefficient} = \frac{V_{11L}\times V_{13T}}{C_{11L}\times C_{13T}}+\frac{V_{21L}\times V_{23T}}{C_{21L}\times C_{23T}}+\frac{V_{33L}\times V_{34T}}{C_{33L}\times C_{34T}}+\frac{V_{44L}\times V_{43T}}{C_{44L}\times C_{43T}}$$

$$=\frac{V_{1L}\times V_{3T}}{C_{1L}\times C_{3T}}+\frac{V_{3L}\times V_{1T}}{C_{3L}\times C_{1T}}+\frac{V_{3L}\times V_{4T}}{C_{3L}\times C_{4T}}+\frac{V_{4L}\times V_{3T}}{C_{4L}\times C_{3T}}$$

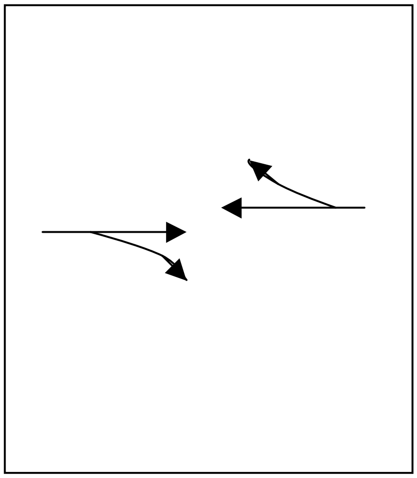
$$=\frac{V_{1L}\times V_{3T}}{1200\times 2400}+\frac{V_{3L}\times V_{1T}}{1200\times 2400}+\frac{V_{3L}\times V_{4T}}{1200\times 2400}+\frac{V_{4L}\times V_{3T}}{1200\times 2400}$$

Phasing Plan 2:

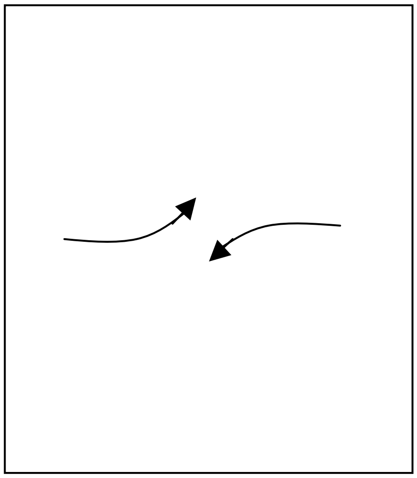
Phase A



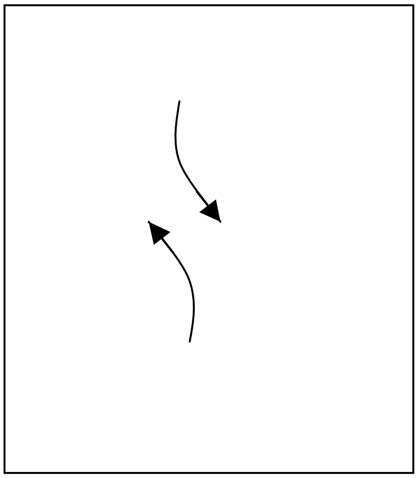
Phase B



Phase C



Phase D



Calculating Phasing Coefficients:

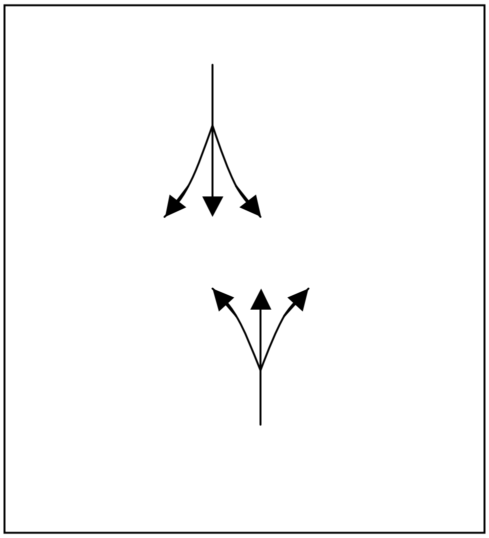
No of conflicts=0

Phasing Coefficient =0.01

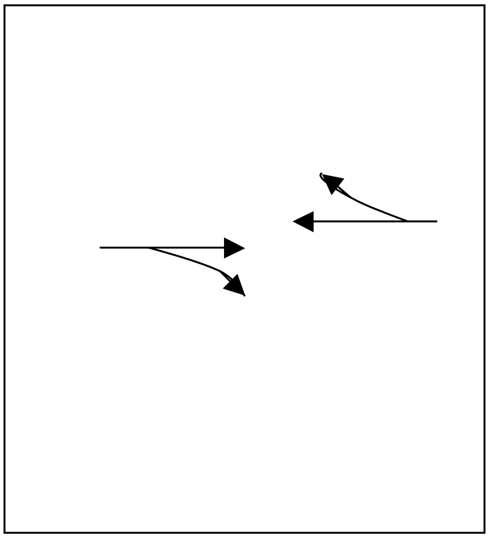
This value is given to the phasing coefficient, as there are other conflicts between right turns and through movement vehicles that were negligible in other cases and are significant here.

Phasing Plan 3:

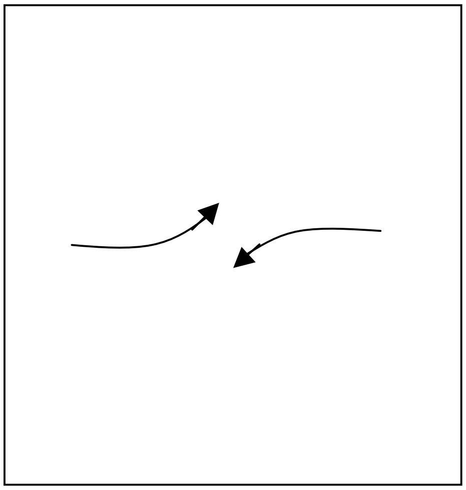
Phase A



Phase B



Phase C



Calculating Phasing Coefficients:

No of conflicts=2

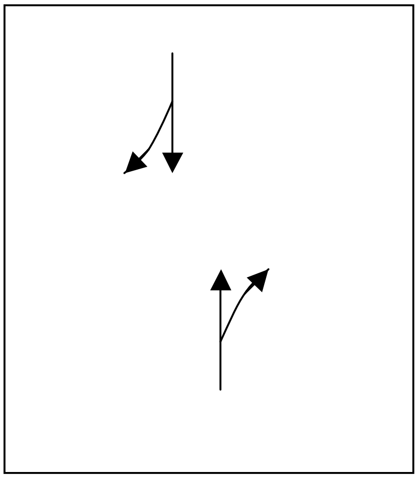
$$\text{Phasing Coefficient} = \frac{V_{11L} \times V_{13T}}{C_{11L} \times C_{13T}} + \frac{V_{23L} \times V_{21T}}{C_{23L} \times C_{21T}}$$

$$= \frac{V_{1L} \times V_{3T}}{C_{1L} \times C_{3T}} + \frac{V_{3L} \times V_{1T}}{C_{3L} \times C_{1T}}$$

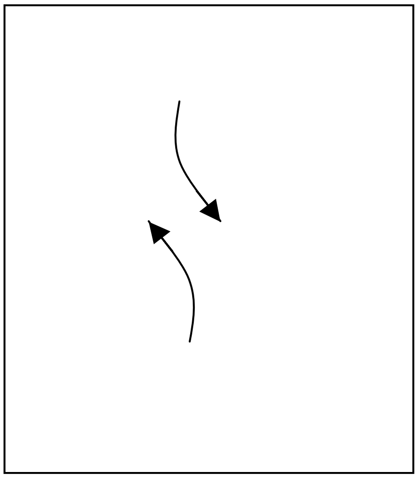
$$= \frac{V_{1L} \times V_{3T}}{1200 \times 2400} + \frac{V_{3L} \times V_{1T}}{1200 \times 2400}$$

Phasing Plan 4:

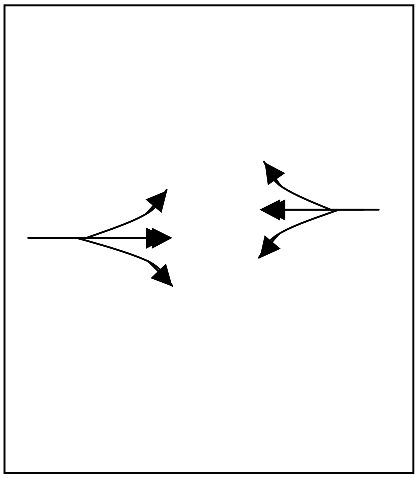
Phase A



Phase B



Phase C



Calculating Phasing Coefficients:

No of conflicts=2

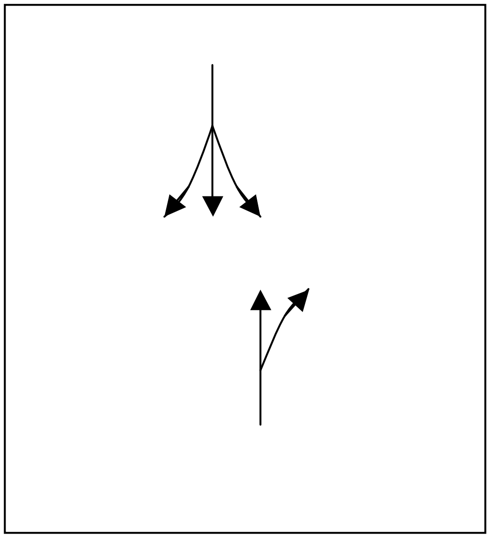
$$\text{Phasing Coefficient} = \frac{V_{14L} \times V_{12T}}{C_{14L} \times C_{12T}} + \frac{V_{22L} \times V_{24T}}{C_{22L} \times C_{24T}}$$

$$= \frac{V_{4L} \times V_{2T}}{C_{4L} \times C_{2T}} + \frac{V_{2L} \times V_{4T}}{C_{2L} \times C_{4T}}$$

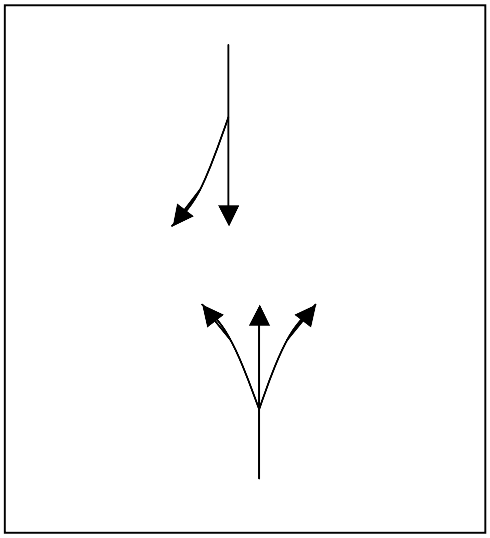
$$= \frac{V_{4L} \times V_{2T}}{1200 \times 2400} + \frac{V_{2L} \times V_{4T}}{1200 \times 2400}$$

Phasing Plan 5:

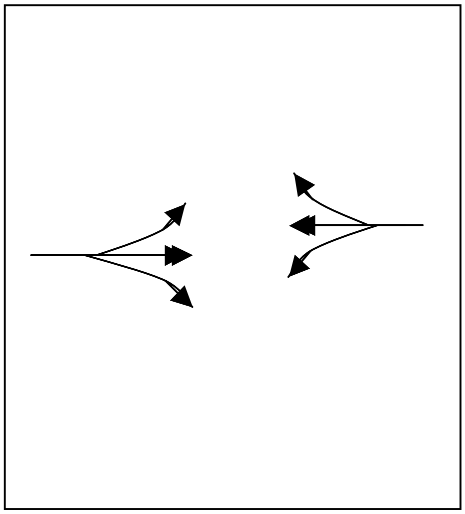
Phase A



Phase B



Phase C



Calculating Phasing Coefficients:

No of conflicts=2

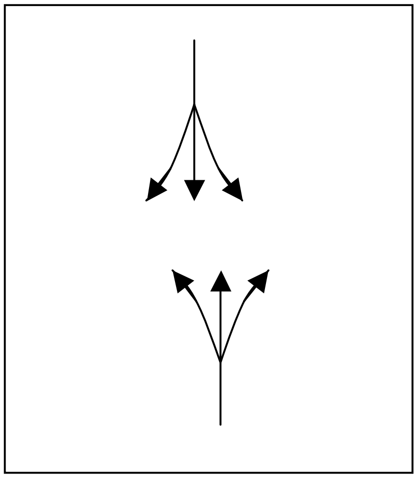
Phasing Coefficient = $\frac{V_{11L} \times V_{13T}}{C_{11L} \times C_{13T}} + \frac{V_{23L} \times V_{21T}}{C_{23L} \times C_{21T}}$

$$= \frac{V_{1L} \times V_{3T}}{C_{1L} \times C_{3T}} + \frac{V_{3L} \times V_{1T}}{C_{3L} \times C_{1T}}$$

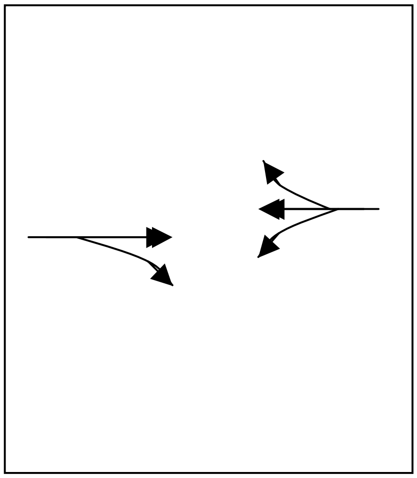
$$= \frac{V_{1L} \times V_{3T}}{1200 \times 2400} + \frac{V_{3L} \times V_{1T}}{1200 \times 2400}$$

Phasing Plan 6:

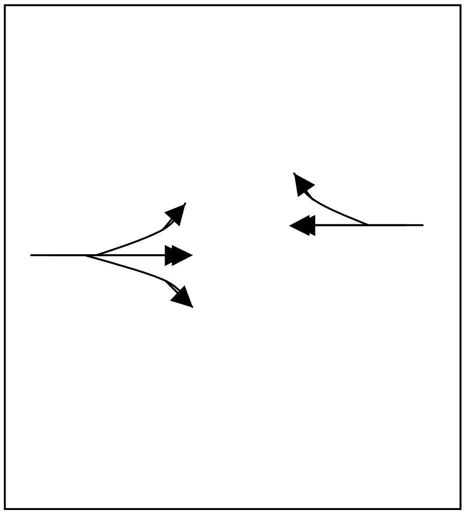
Phase A



Phase B



Phase C



Calculating Phasing Coefficients:

No of conflicts=2

$$\text{Phasing Coefficient} = \frac{V_{14L} \times V_{12T}}{C_{14L} \times C_{12T}} + \frac{V_{22L} \times V_{24T}}{C_{22L} \times C_{24T}}$$

$$= \frac{V_{4L} \times V_{2T}}{C_{4L} \times C_{2T}} + \frac{V_{2L} \times V_{4T}}{C_{2L} \times C_{4T}}$$

$$= \frac{V_{4L} \times V_{2T}}{1200 \times 2400} + \frac{V_{2L} \times V_{4T}}{1200 \times 2400}$$

The following saturation flows were used in the calculation of phasing coefficients,

When $N_{iL} = 0$; $N_{iT} = 1$; $N_{iR} = 0$

S_i=1700

When $N_{1L} = 1$; $N_{1T} = 1$; $N_{1R} = 0$

S_{iL}=1613; S_{iTR}=1800

When $N_{iL} = 0$; $N_{iT} = 2$; $N_{iR} = 0$

S_i=3400

When $N_{iL} = 1$; $N_{iT} = 2$; $N_{iR} = 0$

S_{iL}=1613; S_{iTR}=3600

When $N_{iL} = 0$; $N_{iT} = 3$; $N_{iR} = 0$

S_i=5100

When $N_{iL} = 1$; $N_{iT} = 3$; $N_{iR} = 0$

S_{iL}=1613; S_{iTR}=5400

When $N_{iL} = 0$; $N_{iT} = 1$; $N_{iR} = 1$

S_{iLT}=1700; S_{iR}=1613

When $N_{iL} = 1$; $N_{iT} = 1$; $N_{iR} = 1$

S_{iL}=1613; S_{iT}=1800; S_{iR}=1613

When $N_{iL} = 0$; $N_{iT} = 2$; $N_{iR} = 1$

S_{1iLT}=3400; S_{1iR}=1613

When $N_{iL} = 1$; $N_{iT} = 2$; $N_{iR} = 1$

S_{iL}=1613; S_{iT}=3600; S_{iR}=1613

When $N_{iL} = 0$; $N_{iT} = 3$; $N_{iR} = 1$

S_{iLT}=5100; S_{iR}=1613

When $N_{1iL} = 1$; $N_{1iT} = 3$; $N_{1iR} = 1$

S_{iL}=1613; S_{iT}=5400; S_{iR}=1613

Appendix C

The Coefficients From Desirable Quantity Index of Färe's index model

The following table contains all the coefficient valued solved from the linear program for the desirable quantity index from Färes' index model. This table is referred to in Chapters 4 and 5.

DMUs	54	53	52	51	49	48	47	46	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	55	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	3	2
Q_p	1.246718	1.415204	1.175159	1	1.515065	1.159843	1	1.086111	1.266334	1.147448	1	1.296909	1	0	1.42666	1	1.160165	1.234646	1.203774	0	1.072825	1	1.48828	1.229866	1	1.31154	1.011013	1.154615	1	1	1.166614	1.223255	1.219057	1	1.433526	1.031785	1.098262	1.078494	1	1.233405	1.458959	0	1.197554	1.10319	1	1.40543	1.0416	1	1.210449	1
Z_{54}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{53}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{52}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{51}	0	0	0	1	0	0	1.58E-12	0	0	0	0	0	0	0	0	1.23E-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{49}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{48}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{47}	0	0.443667	0	0	0	0.271553	1	0	0	0	0	0	0	0	0	5.39E-12	0	0	0.207225	0	0	0	0	0.01951	2.84E-12	0	0	0	5.76E-11	0	0.464395	0	0	2.2E-12	0	0	0	0.276371	8.64E-13	0	0	0	0	0	0	0	0	0	0.111907	2.14E-12

Z_{46}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{44}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{43}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{42}	0.001327	0	0.246756	0	0.573702	0	0	0	0.384051	0.221731	1	0.338896	0	0	0.261546	0	0.821184	0.156174	0	0	0.416546	0	0.942413	0	0	1.072162	0	0	0	0	0	0	0	0	1.259916	0	0	0.080661	0	0	0	0	0.862583	0.075257	0	0.850765	0	0	0.974748	0
Z_{41}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{40}	0	0.199737	0.801412	0	0.385754	0.840886	0	0	0.660102	0.622541	0	0.611792	1	0	0.016932	0	0.294824	0.777184	0.758009	0	0.191473	0	0.070039	0.930131	0	0	0.321648	0	1.79E-10	0	0	0	0	4.71E-13	0	0.019971	0	0.770378	0	0	0.343545	0	0.059158	0.750764	0	0	0.108456	0	0	0
Z_{39}	0	0	0.162399	0	0.075008	0	3.51E-12	0.287236	0.417969	0.172966	0	0	0	1	0	0	0	0.18233	0	8.67E-13	0	0	0.32395	0	0	0.083386	0	0.927158	0	0	0.276821	0	0.35398	0	0.085611	0	0	0.062112	0	0	0	0	0	0.048558	0	0	0	0	0	0
Z_{38}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{37}	0	0.173834	0	0	0	0	0	0	0	0	0	0	1.05E-12	0	0	1	0	0	0	0	0	0	0	0	0	0	0.390064	0	0	4.21E-11	0	0.042822	0	0	0	0	0	0	0	0	0	0	0	0	1.99E-12	0	0.479306	0	0	0
Z_{36}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{35}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{34}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{33}	0	0	0	1.15E-11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0.171791	0	0	0	0	0	0	0	0	5.59E-12	0	0	0	0	0	0	0	0

Z_{32}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{31}	0.95060606	0	0	0	0	0	0	0	0	0	6.9E-12	0	0	0	0.945169	0	0	0	0	0	0	1	0	0	1.97E-11	0	0	0	3.06E-10	5.49E-12	0	0.575099	0	0	0	0.295144	0.700259	0	0	0.808935	0.594108	0	0.302611	0	1.42E-11	0.433606	0	0	0.306975	0
Z_{30}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{29}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{55}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.35E-12	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0.40668	0	0	0.120622	0	0	0	0	0	0	0	4.28E-12	0	1.05E-10
Z_{27}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{26}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{25}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{24}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.038551	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{23}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.104838	0	0	1	0	0.018349	0	0	0	0.451239	0	0	0	0	0.109196	0	0	0	0	0	0	0	0	0
Z_{22}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{21}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{20}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{19}	0	0.60	0	0	0	0.00	0	0	0	0	0	0	2.45	0	0	0	0	0	0.02	0	0	0	0	0.04	0	0	0	0	0	0	0.07	0	0.64	1	0	0	0	0	0	0	0	0	0	0	0	0	0.24	0	0	0

		5354				2011							E-13						4664					0144							7306		7802														8205			
Z_{18}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{14}	0	0	0	0	0	0	0	0.857348	0	0	0	0	0	0	0	0	0	0	0	0	0	9E-12	0	0	0	0.203686	0	0.805365	0	0	0	0	0	0	0.304904	0	0.103353	0	1	0	0	0	0	0	0	0	0	0	0.021194	0
Z_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	1.85E-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Z_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2E-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Z_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z_5	0.021985	0	0	0	0	0	0	0	0	0	1.81E-13	0.023344	0	0	0	0	0.186105	0	0	0	0.396152	0	0	0	0	0	0.345562	0	0	0	0	0.483098	0	0	0	0.205729	0	0	0	0.135059	0.176243	0	0.008073	0	1.29E-11	0.327329	0	1	0	0
Z_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Z_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.24E-11	0	0	0	0	0	0	0	0	0	0	0	0	0	1.17E-11	0	0	0	0	0	0	0	0	0	0	1

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I was greatly influenced by the chemistry teacher in my high school. I am greatly indebted to him for having shaped me who I am. I am very fortunate to have such wonderful parents that have sacrificed so much in their lives to support me to get on track to realize my dreams.