OPTIMIZING RAMP METERING STRATEGIES

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Background

- Ramp control is the application of control devices like ramp signals to regulate the number of vehicles entering the mainline from feeder arterial networks through on-ramps.

- This restrictive measure is to achieve operational efficiency and optimum freeway operation in terms of
  - Mainline travel time, travel speed and travel delay.
  - Enhancing traffic safety.

- The study focuses on comparing multiple ramp metering control measures and how each fares in providing the most efficient mainline and ramp flow by:

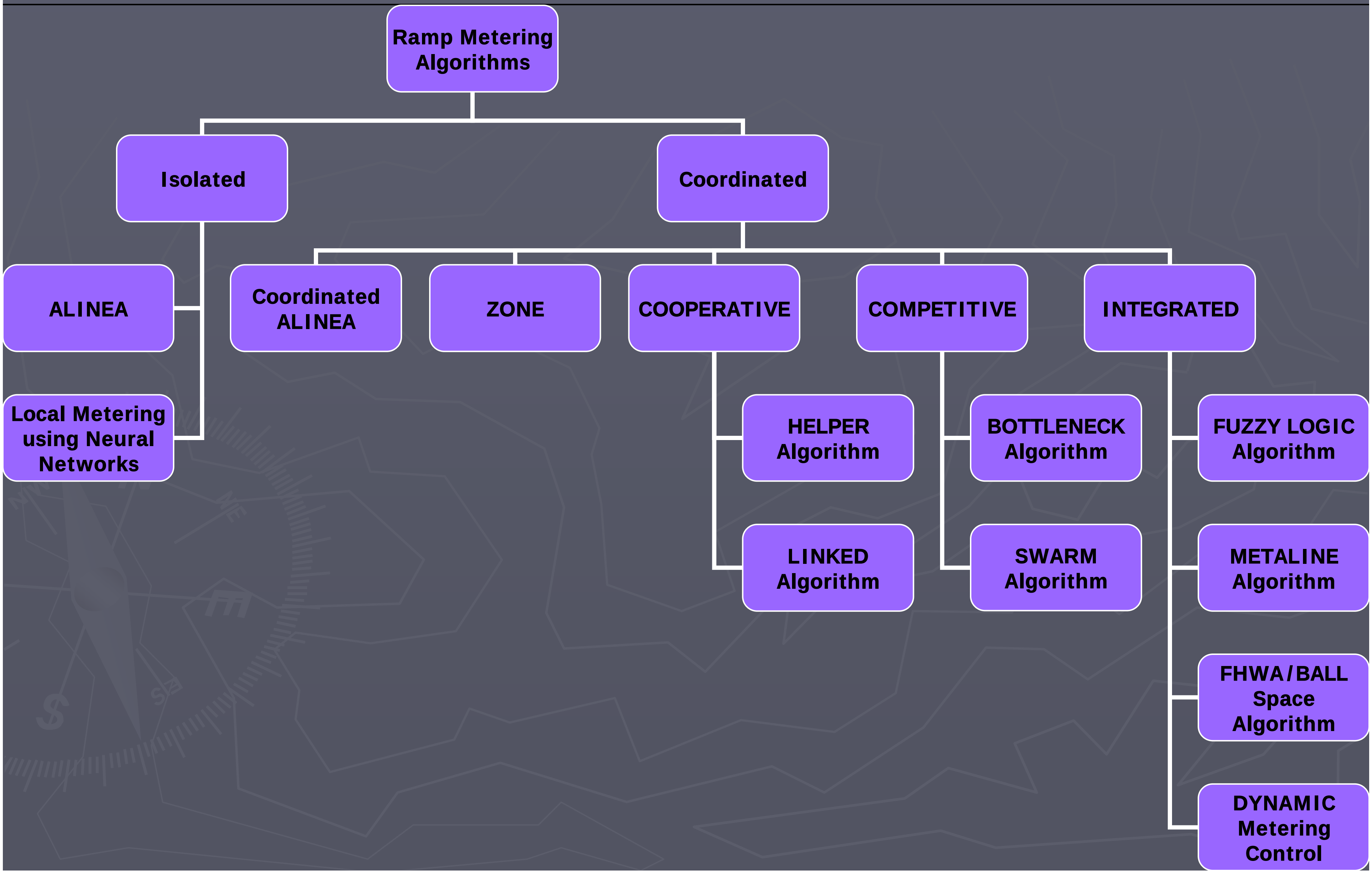
1. Maintaining capacity flow and preventing formation of bottlenecks on the mainline.
2. Preventing excessive queue formation on on-ramps and
3. Preventing spillback into feeder arterial network.

Study Objective

- Ramp control measures which have been researched in this study are:
  1. Base Condition of No Ramp Meter (Open Ramp)
  2. Fixed Time Meter – 4 sec Cycle with 1.5 sec Green
  3. Coordinated ALINEA Algorithm
  4. ZONE Algorithm

- Objective is to determine the most efficient ramp control method in terms of mainline travel time, travel speed and travel delay with respect to the study area along Dan Ryan Expressway.

Ramp Metering Control Methods



ALINEA Algorithm

- Local traffic responsive algorithm in which the control logic is based on the feedback structure from the mainline loop detectors.
- The feedback control logic dynamically maintains the mainline occupancy level below the target occupancy level by restricting the inflow from on-ramps.
- Easy to calibrate and implement in field.
- Queue override feature can be incorporated in the algorithm if required.

ALINEA Algorithm...(contd)

$$r(t) = r(t-1) + K_R * (O_{desired} - O_{downstream}(t))$$

r(t)	Metering rate at timer interval '**t**' (veh/hr)
$\mathbf{O_{desired}}$	Desired occupancy rate of the downstream detector station (%)
$\mathbf{O_{downstream}(t)}$	Measured occupancy rate at the downstream detector station (%).
r(t-1)	Measured on-ramp volume for time interval t-1 (veh/hr).
$\mathbf{K_R}$	Regulator parameter (veh/hr), typically set at 70 veh/hr.

Zone Algorithm

- First implemented by Minnesota Department of Transportation (MnDOT) in the St. Pauls area of Minneapolis.

- A type of coordinated algorithm which is based on the control logic of equating the input into a zone to the output from the zone and thus operate the mainline at capacity.

- Pseudo code of the ZONE algorithm:

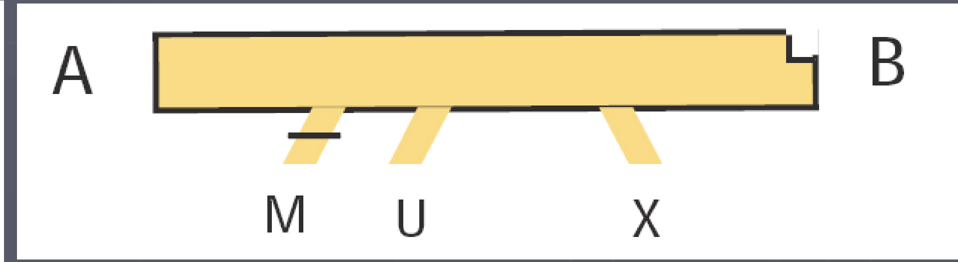
  - Divide the corridor into multiple zones based on location of critical bottlenecks in the corridor - u/s end of the zone is a free flow and the d/s is the critical bottleneck.

  - Regulate the inflow from the on-ramps so as to smooth out the congestion and then allow the traffic on the mainline to move at capacity.

Zone Algorithm...(contd)

A + U + M + F = X + B + S

A	upstream mainline volume – measured value
U	sum of the volumes from non-metered entrance ramps in the defined zone - measured values
M	sum of the volumes from the metered entrance ramps in the defined zone - to be calculated by the algorithm
F	sum of the measured freeway to freeway volumes - to be calculated
X	is the sum of the exit ramp volumes – measured value
B	downstream bottleneck capacity - calibrated value
S	space available in the ZONE – assumed to be zero for capacity performance



Bottleneck Algorithm

- Implemented by the Washington Department of Transportation in the Seattle region.
- A type of coordinated algorithm in which the network is divided into sections based on bottleneck locations.
- The control logic has a two tier structure:
  - Local
    - Real-time upstream demand is compared to the downstream capacity and the difference is the local metering rate for the ramp.
  - Global
    - Coordinate control strategy identifies bottlenecks and computes the volume reduction required at the bottleneck based on flow conservation.
    - Algorithm distributes volume reduction according to predetermined weights based on the criticality of the ramp.
- Once the two rates are computed, the more restrictive of the two is the metering rate for the ramp.

SWARM Algorithm

- Implemented in the Orange County region of California.
- A coordinated algorithm that maintains the real-time mainline density below the defined saturation density.
- Like the bottleneck algorithm has a two tier control logic:
  - Local metering rate
    - Based on local density near the ramp merge.
  - Global metering rate
    - Base volume reduction on ramps upstream of a **PREDICTED** bottleneck , instead of measured conditions.
- The more restrictive of the two rates is implemented. The pro and the con of the algorithm being:
  - Pro – SWARM predicts the location of bottlenecks in the network based on predicted traffic volume and flow patterns thus making it a more preventive measure rather than a reactive one.
  - If prediction is poor, the algorithm can produce worse failure than bottleneck which is more based on measured volumes.

Micro-simulation - Types of Models

- **Macroscopic Models:**
  - Takes into account a more system wide representation of traffic flow and characteristics
- **Mesoscopic Models:**
  - Platoons or groups of vehicles are taken as an unit of analysis without any consideration of the inter-vehicle interaction.
- **Microscopic Models:**
  - Individual vehicle characteristics can be calibrated and the inter-vehicle interactions can be studied.

Simulation Platform – VISSIM 4.1

- Microscopic traffic simulator that has been used to analyze the effect of the ramp metering algorithms as applied to the study bed.

- Microscopic simulators like VISSIM provide the following features like:

  - Mechanical and other characteristics like speed, acceleration rates etc. can be calibrated for each of the vehicles, thus providing an accurate simulation of the real world.

  - Inter-vehicle interaction in terms of following distance, headway and driver characteristics like aggressive or passive driving behavior can also be calibrated.

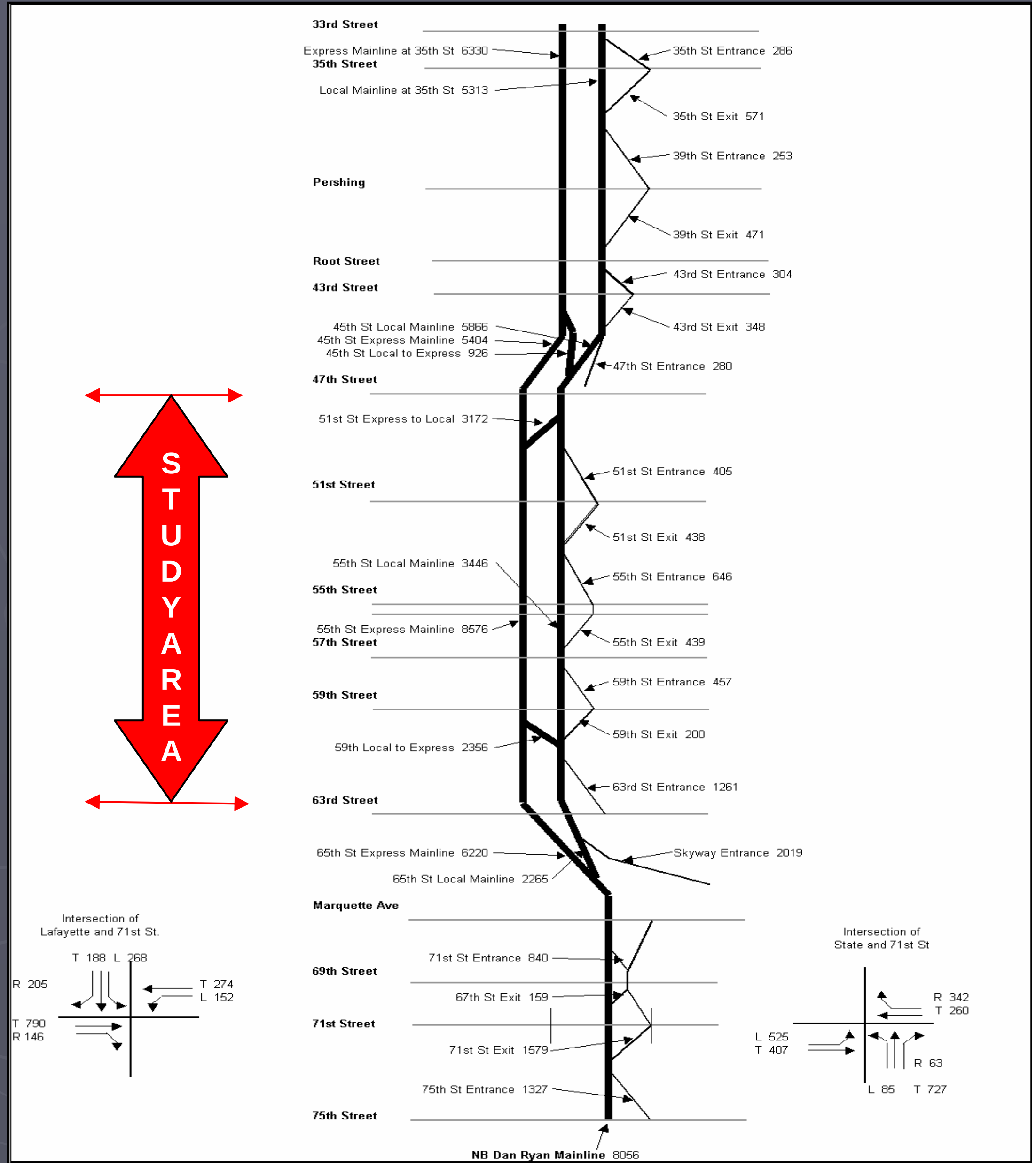
- Simulation models and related studies are useful for cost effective impact studies like in this case.

VISSIM 4.1...(contd)

- Network Elements Calibrated in Study:
  - **Mainline Loop Detectors:** Location of the mainline loop detectors was critical for achieving proper control.
  - **Signal Control:** To implement the ramp control logic, the ramp signal heads were calibrated to simulate the following conditions:
    - No Ramp of Open Ramp
    - Fixed-time Control with a Cycle of 4 sec and a green time of 1.5 sec
    - Adaptive Isolated and Coordinated Algorithms using Vehicle Actuated Programming (VAP) which is a programmable interface for implementation of adaptive control algorithms like:
      1. **ALINEA**
      2. **ZONE**
  - **Travel Time Measuring Zones:** Travel Time Zones were calibrated for collecting the mainline travel time and travel delay.
  - **Data Collection Points:** The data collection points are defined to collect counts of vehicles crossing the section and other related data.

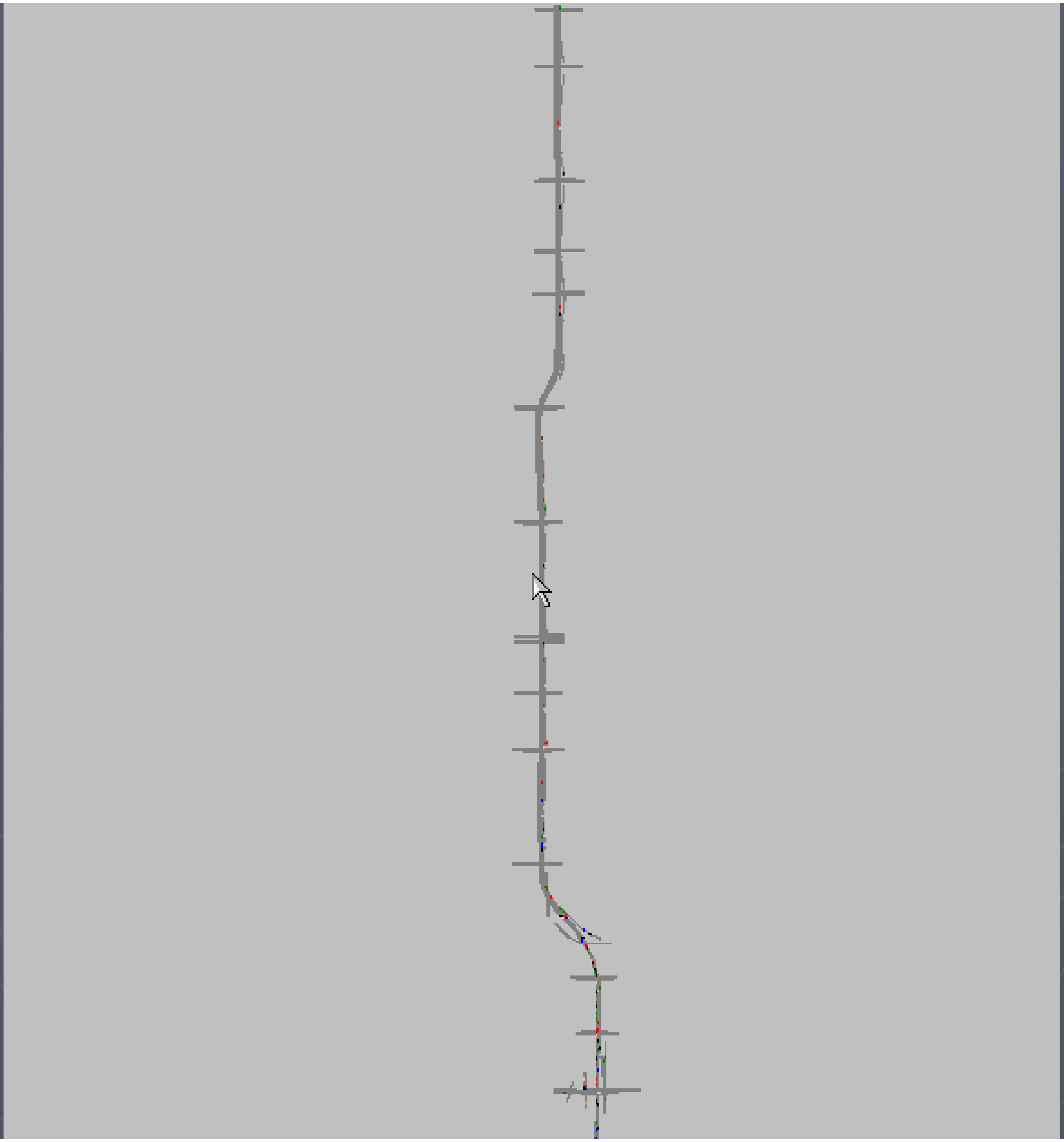
Study Area – Dan Ryan Expressway

- 1.85 miles along the NB Local lanes of the Dan Ryan Expressway from the 63rd street on-ramp to the 51st street on-ramp as shown.
- 4 on-ramps in the corridor – 63rd, 59th, 55th and 51st streets.
- 3 off-ramps in the corridor – 63rd, 59th and 55th street
- Transfer Lanes from local to express lanes near 63rd street merge.
- Transfer Lanes from express to local near 51st street merge.



Calibration of Network Parameters

- Throughput target volume is based on IDOT's Traffic Systems Center (TSC) data.
- Target occupancy rate (ALINEA) and bottleneck capacities are based on floating car studies and field data collection.
- Study Elements
  - **Uncontrollable Elements:** Uncontrollable elements involved in the study included:
    - geometry of the study area.
    - input traffic volumes and traffic routing.
    - signal timings and traffic composition in the corridor.
  - **Controllable Elements:** Controllable elements of the network which were changed to simulate the real field situation in the study included:
    - Lane change parameters regarding the location where traffic starts changing lanes.
    - Car following behavior and driver perceptive reaction to reflect aggressive Chicago driving behavior.
    - Simulation resolution – number of times per simulation second a vehicle's position is calculated



Simulation & Testing

- Approaches: Two separate testing approaches were implemented in the study for evaluating the performance of each of the ramp control measures-

  1. Fixed Increment: The mainline traffic being increased from base volume by 500 veh/hr and 1000 veh/hr.

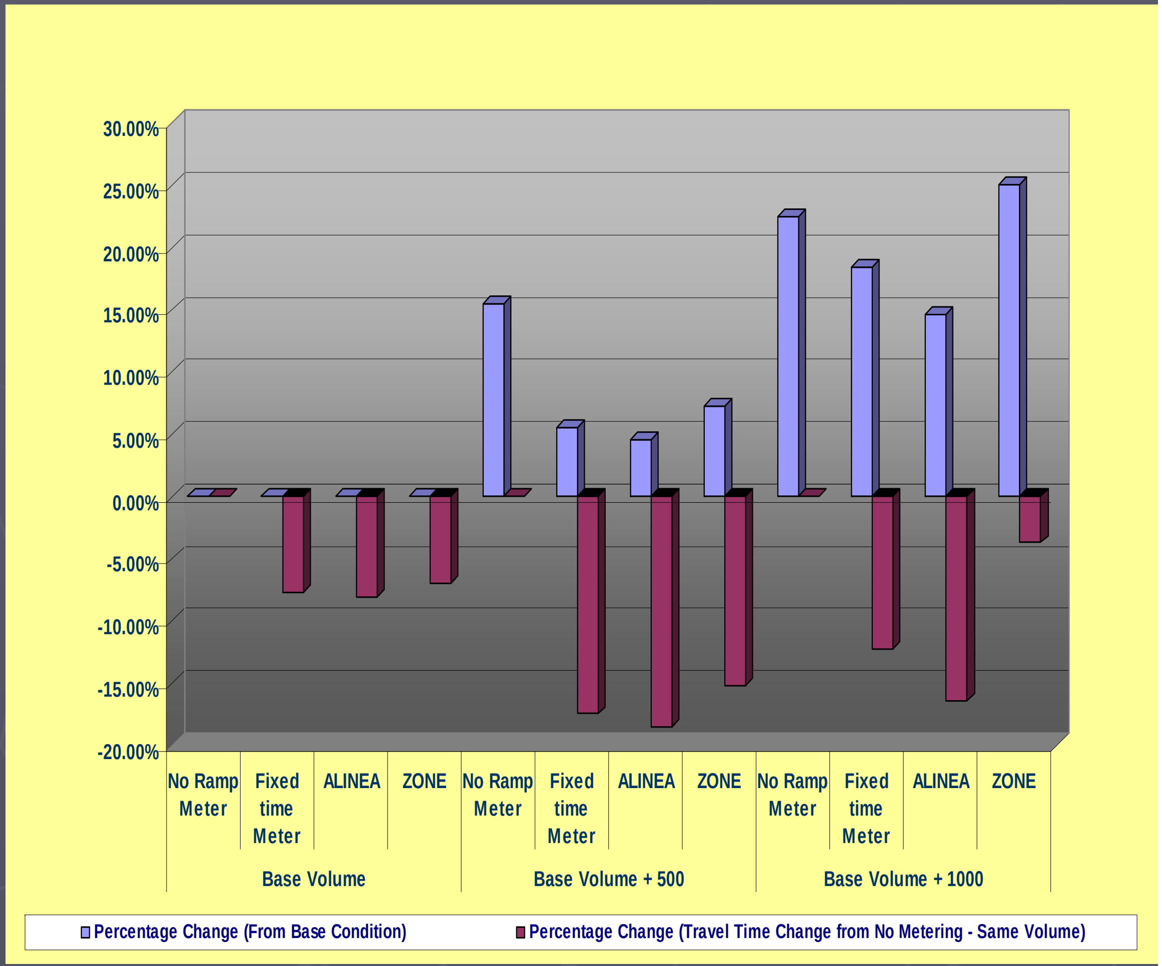
  2. Percentage Increment: Both the mainline and the ramp volumes were increased by 5%, 10% and 15% of the base volume on the mainline and ramp respectively.

- For both the test scenarios, the mainline performance in each of the four control methods was evaluated with respect to:

  1. Mainline Weighted Travel Time
  2. Mainline Weighted Travel Speed
  3. Mainline Weighted Travel Delay

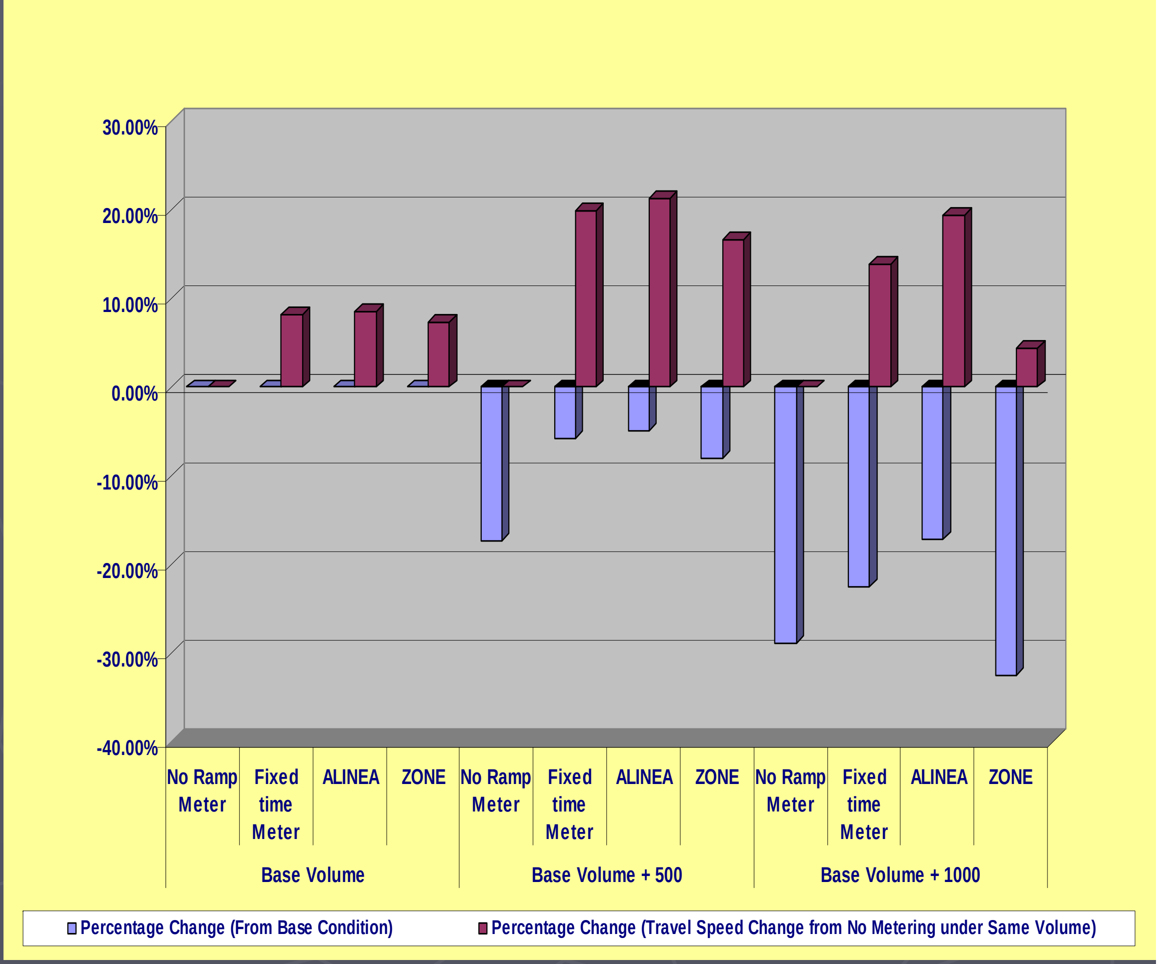
Results – Mainline Travel Time

- ALINEA provided the lowest mainline travel time under all traffic volume conditions.
- Fixed Time metering provided very close performance in terms of mainline travel time.



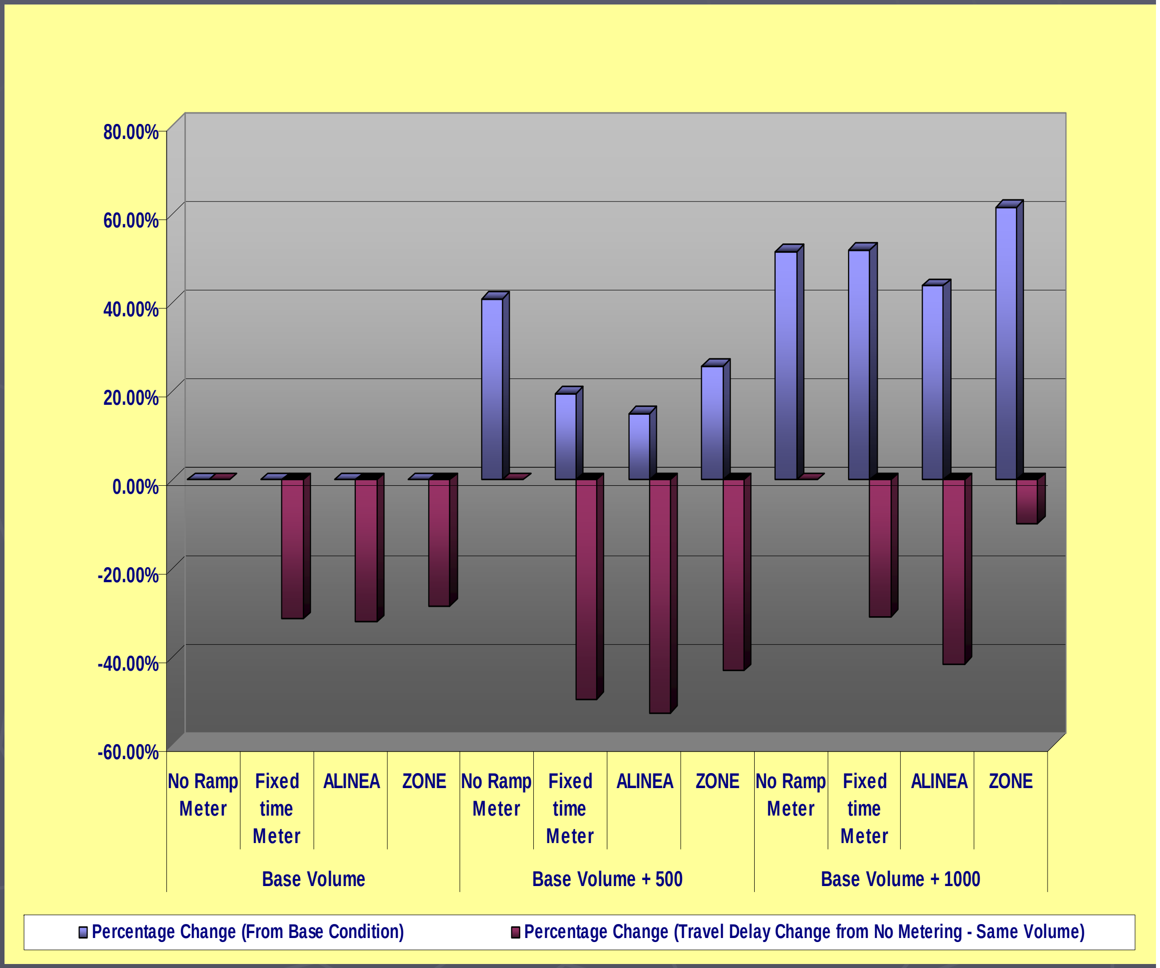
Results – Mainline Travel Speed

- ALINEA provides the highest mainline travel speed even in high traffic volumes, almost close to 33 mph at 15% higher mainline volumes.
- ZONE proved to be the least effective ramp control mechanism in the study corridor.



Results – Mainline Travel Delay

- In terms of mainline travel delay ALINEA performs best when the corridor is operating at additional 7% of base volume.
- At an additional 15% volume, ALINEA performs marginally better. Fixed time metering performs at same level as open ramp.



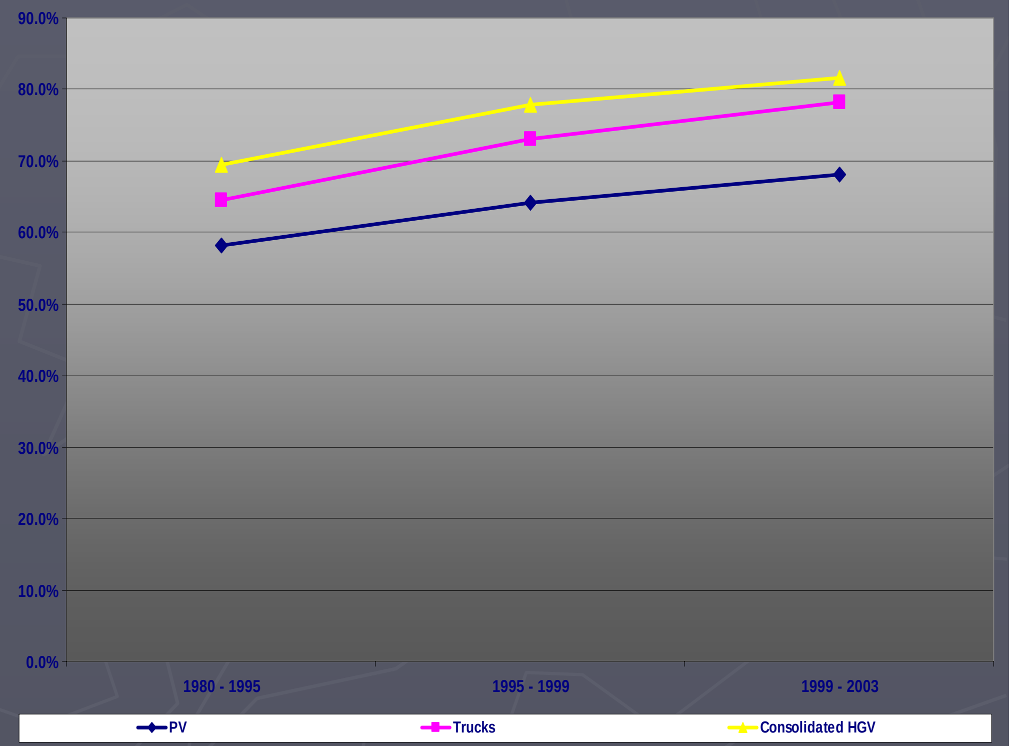
Consolidated Ramp Metering Measure Performance

- Among the new control algorithms, ALINEA performs best in terms of all measures of effectiveness (MOE).
- Additional test conditions involving the increment in the mainline and the on-ramp volume by 5%, 10% and 15% of the current (base) volume were also simulated. ALINEA proved to have a similar performance over other ramp control measures.
- Fixed Time metering as implemented by IDOT currently, provides good control at traffic demand levels.
- In the study, ZONE performs poorly with respect to MOEs in spite of its inherent strengths. One reason for this is the close spacing of the on-ramps and the general geometry and traffic characteristics of Dan Ryan.
- Overall, ramp metering is justifiable. Depending on local conditions and control measures implemented, the benefits can be quantified as:

    1. Reduction in mainline travel delay by 10% to 50%.
    2. Reduction in mainline travel time by 7% to 19%.
    3. Increase in the mainline travel speed by 5% to 22%.
    4. Provide a equitable balance between mainline traffic flow and traffic inflow from on-ramps.

Optimum Fixed Green Time for HGV Operations - Background

- FHWA national VMT statistics have shown the following key facts regarding HGV operations in the country since 1980:
  - 1980 – 1995: 58.2% increase for Passenger Vehicles (PV) and 64.2% increase for trucks (HGV); Combination HGV shows a 68.1% increase.
  - 1995 – 1999: 10.9% increase for PV and 13.8% increase for HGV; Combination HGV shows a 14.7% increase.
  - 1999 – 2003: 7.6% increase for PV and 6.5% increase for HGV; Combination HGV shows a 4.5% increase.



- The figures absolutely prove that truck travel is outgrowing passenger car travel in terms of VMT and this trend is going to continue with economic growth and GDP growth.
- It is therefore required to cater to the demands of the growing truck population on the nations highways.

HGV Operation – Simulation Observations

- During the simulation runs, it was visually observed:
  - Current fixed green times 1.5 sec was insufficient for HGVs, that have stopped at the ramp signal head, to accelerate and merge with the mainline traffic.
  - In case of high HGV volume ramps, this led to queue buildup on the ramp with faster moving passenger cars waiting behind and spilling back into arterial network.
- To counter this, several measures can be taken like:
  - **HGV Specific Lanes** – Ideal for segregation of traffic but involves major capital investment in terms of new design and construction.
  - **Priority Signal for HGV** – Dynamic method of altering the green signal timing depending on the detection of HGV. But this involves implementation of adaptive signaling methods.
  - **Altering Fixed Green Time** – Least expensive method of enabling a smooth HGV flow. It can have adverse effects on the mainline and so careful study is required to justify the trade-off.
- The effect of altering the on-ramp fixed green time has been analyzed in this study.

HGV Operation Study Framework

- Study was conducted on the 63rd street on-ramp which, as per the traffic volume data from IDOT, has the highest HGV volume.
- The current base volume of HGV on the 63rd street on-ramp is around 6% of the total traffic volume.
- The test scenarios intended to test the mainline and ramp performance in terms of:
  1. Average mainline and ramp travel time.
  2. Average mainline and ramp travel speed.
  3. Average mainline and ramp travel delay.
- The ramp HGV volume was increased 5% and the performance was measured with the HGV volume at base, 5%, 10% and 15% of the total ramp traffic volume.
- The fixed green time on the ramp signal head was increased from the base timing of 1.5 sec in intervals of 0.5 sec till 3.0 sec, and the system performance was tested at 1.5 sec, 2.0 sec, 2.5 sec and 3.0 sec fixed green time.

HGV Operation Study Results

- Based on the simulation runs, for varying levels of HGV volumes on the 63rd street ramp, the following results were obtained for the MOEs:

Consolidated Travel Time - 63rd On-Ramp (sec)

		Fixed Time Green			
		1.5 Sec	2.0 Sec	2.5 Sec	3.0 Sec
On-Ramp HGV Volume	Base	73.09	62.46	34.62	58.49
	Base + 5%	81.43	63.45	35.04	57.59
	Base + 10%	89.15	64.18	37.87	56.74
	Base + 15%	93.91	64.78	40.17	56.47

Consolidated Travel Speed - 63rd On-Ramp (mph)

		Fixed Time Green			
		1.5 Sec	2.0 Sec	2.5 Sec	3.0 Sec
On-Ramp HGV Volume	Base	5.4	6.3	11.5	6.8
	Base + 5%	4.9	6.2	11.4	6.9
	Base + 10%	4.4	6.2	10.5	7.0
	Base + 15%	4.2	6.1	9.9	7.0

Consolidated Travel Delay - 63rd On-Ramp (sec)

		Fixed Time Green			
		1.5 Sec	2.0 Sec	2.5 Sec	3.0 Sec
On-Ramp HGV Volume	Base	59.8	49.2	21.3	45.2
	Base + 5%	68.1	50.1	21.7	44.3
	Base + 10%	75.8	50.9	24.6	43.5
	Base + 15%	80.6	51.5	26.9	43.2

Consolidated Travel Time - Study Corridor (sec)

		Fixed Time Green			
		1.5 Sec	2.0 Sec	2.5 Sec	3.0 Sec
On-Ramp HGV Volume	Base	162.12	163.12	175.71	164.48
	Base + 5%	162.35	163.98	180.85	167.05
	Base + 10%	162.28	164.44	178.85	166.43
	Base + 15%	161.05	164.47	192.35	168.74

Consolidated Travel Speed - Study Corridor (mph)

		Fixed Time Green			
		1.5 Sec	2.0 Sec	2.5 Sec	3.0 Sec
On-Ramp HGV Volume	Base	35.1	34.9	32.4	34.6
	Base + 5%	35.0	34.7	31.5	34.1
	Base + 10%	35.1	34.6	31.8	34.2
	Base + 15%	35.3	34.6	29.9	33.7

Consolidated Travel Delay - Study Corridor (sec)

		Fixed Time Green			
		1.5 Sec	2.0 Sec	2.5 Sec	3.0 Sec
On-Ramp HGV Volume	Base	29.8	30.7	43.0	32.1
	Base + 5%	30.2	31.7	48.0	34.6
	Base + 10%	30.2	32.1	46.0	34.0
	Base + 15%	29.0	32.2	59.6	36.3

HGV Study – Conclusions

- From the consolidated results tabulated above it can be concluded that:
  - For the traffic and geometric specific to the 63rd street on ramp, a 2.0 sec fixed green time provides the maximum equitable benefits in terms of on-ramp and mainline travel time, speed and delay.
- Data thus obtained from the simulation runs provides a policy tool for altering the fixed green time on the ramps depending on the local traffic conditions.
- However, it is required to prioritize the severity of the impact on the on-ramp and the mainline. Only after careful study and cost analysis of both the positive and negative impacts of the changes should the green time be altered.

Summary of Study Results

- Based on algorithm study conducted on the Dan Ryan, the following results can be concluded:

  - Ramp metering absolutely improvement in the overall network performance with respect to travel time, travel speed and travel delay over no-metering scenario as can be summarized as below:

    1. Reduction in mainline travel delay by 10% to 50%.
    2. Reduction in mainline travel time by 7% to 19%.
    3. Increase in the mainline travel speed by 5% to 22%.
    4. Provide a equitable balance between mainline traffic flow and traffic inflow from on-ramps.

  - The degree of improvement depends on the local traffic and geometric conditions.
  - The overall performance of the ramp control measures can be ranked as:

    1. Coordinated ALINEA
    2. Fixed Time Metering
    3. ZONE

  - Under the current traffic volume condition, the IDOT metering rate of 1.5 sec green time at the study site performs well. But with increasing mainline volumes, as was observed, the performance of fixed time metering deteriorates and other alternative methods of ramp control need to be considered.

Summary of Study Results...contd

- **Based on the HGV study conducted, the following can be concluded:**
  - **Under the current HGV volumes, a fixed green time of 1.5 sec provides acceptable levels of performance.**
  - **With increase in HGV volumes, both the ramp and mainline performance is going to deteriorate and thus it is required to increase the fixed green time.**
  - **A 2.0 sec fixed green time provides an equitable balance between the mainline and ramp performance.**