Re-validating and Improving Queue Length Models at Two-Way Stop Controlled Intersections

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Executive Summary

An effort to document the inconsistencies among the queue length estimation methods at two-way stop controlled intersections took place in the year 2010. The 2010 study models significantly improved the queue estimates except for major left turn configuration. The models are predicting over 65 percent of variability and most part used data from ODOT region 1 and region 2. One of the study recommendations is to expand the database and improve the model estimates.

Hence, the study again revisited with the aim to improve queue length models at two-way stop controlled intersections. Data covering various functional classifications of highways, geometric configurations, and geographic regions were collected by using video tapes. Still, previous models are performing well for 2013 data over other methods and models. The present study develops new models using 2013 data to foster the understanding of queue behavior on both major and minor approach lane groups. Various regression models were fitted to explain the random process in queue lengths. A model comparison shows significantly improved performance of the new models in predicting maximum queue lengths except for few lane groups where the 2010 model is predicting better queue lengths.

After introducing the problem, data collection and analysis efforts are presented. Next few sections explain the model selection and validation for each lane group configuration following the methodology outline. Last section concludes with recommendation of model forms for QL estimation.

1 Introduction

An effort to develop alternative models for estimating two-way stop controlled (TWSC) intersection queue lengths in the state of Oregon took place in the year 2010. Significant improvements in terms of predicting queue lengths over other analytical procedures were achieved. However, the 2010 report recommended continuation of the study. In specific, sample coverage and size were envisioned to improve the model performance. Also, model predictability, which hovers between 60 to 70 percent, has the potential to be improved by increasing the variability of the explanatory variables. In this continuation study, queue length models are re-estimated and validated with a broader range of traffic, queue lengths, geometry and other conditions.

2 Data Collection and Analysis

Data collection sites by region, shown in Appendix A, were screened using Traffic Count Management (TCM) software and aerial imagery. Queue Length (QL) was defined as the maximum number of vehicles in the queue during the study period (one hour) as collected from traffic count videos1. Hourly traffic volumes from TCM and geometry from aerial images were collected for the screened sites. Unlike the 2010 dataset, the number of heavy vehicles and their percentage in traffic, and conflicting lanes for the subject lane groups, were also collected as an expansion to the set of explanatory variables (listed in Table 1).

[1] Intersection videos, stored in Blu-ray disk format, show queues which are manually recorded for the study time period

Table 1. List of Explanatory Variables Considered for 2013 Data Analysis

Category	List of Explanatory Variables
Geometry	Number of approaches (Number of legs) Lane groups Number of lanes on both major and minor approaches Conflicting lanes for the subject lane group Lane configuration (shared/separate) Channelization / Flared approaches Median Type Intersection Skewness Presence of Two Way Left Turn (TWLT) / exclusive left lanes
Operations	Approach speed Upstream Signal within 1/4 mile
Traffic Flow	Approach volume Conflicting volume Turning volume Number and Percent of heavy vehicles by turning movement

Intersections were chosen to cover a range of lane configurations, geographic regions, functional classifications, and traffic conditions. In total, the study collected data from 38 intersections. Unlike the 2010 study, this study focused more on collecting data from regions other than Region 1. As illustrated in Figure 1, slightly more than half of the intersections are from Region 3. All of the data collected were from counts taken over the past three years.

The maximum number of vehicles in the stopped queue was collected for every one hour interval covering both peak and off-peak periods for each lane group. Traffic volumes for the same period were obtained from TCM. The next step was to calculate the conflicting traffic flow rate according to the procedure documented in the 2010 Highway Capacity Manual (HCM). Conflicting volume from individual movements in a lane group are added algebraically to obtain the lane group conflicting movements. Similarly, lane group volumes are obtained by adding individual lane volumes in that lane group. In addition, the study estimated queue lengths by the two-minute rule, HCM methodology, and Gard's equation for comparative purpose.

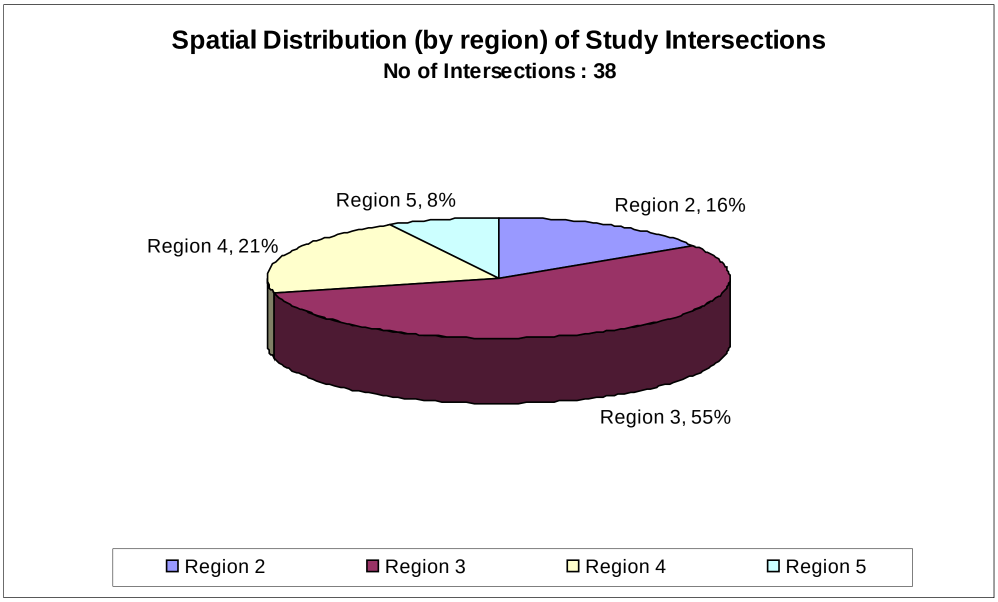

Figure 1. Distribution of Study Intersections by ODOT Region

3 Methodology

The 2010 Highway Capacity Manual (2010 HCM) ranks/ prioritizes the movements at TWSC intersections for capacity, delay and queue length estimation. Like the 2010 model, this study estimated queue lengths by lane groups. Apart from MJL (major left), MNLTR (minor shared left, through and right), and MNLR (minor shared left and right), the study also considered MNL (minor left), MNR (minor right), and MNTR (minor shared through and right) lane configurations. Statistical modeling using the QL as the dependent variable and a combination of explanatory variables (listed in Table 1) as independent variables was performed for each lane group. A summary of models for the given dataset was tabulated for each lane group. The best performing models were selected based on the significance of the model and its parameters. Once the models were selected, they were validated using a part of the 2013 data. The difference in queue lengths between the models and observed were calculated. This study used a difference of ± 1 vehicle as the acceptable range, a difference greater than + 1 vehicle labeled as over-estimated, and less than – 1 vehicle treated as under estimated. Data on percent of acceptable, under estimated and over-estimated queue lengths was used for models comparison. The next few sections outline the model estimates and comparisons.

4 Major Left (MJL) Lane Group Analysis

First, the analysis dealt with an assessment of the 2010 MJL model for the data collected in the year 2013. The assessment included a comparison of the 2010 MJL model estimates with the observed queue lengths, and a cross comparison with the estimates from the two-minute rule, HCM methodology, and Gard's equation. The difference between the model(s) and observed QLs was used to compare the models. Approximately 77 percent of the 2010 model estimates were within the acceptable range. The 2010 model estimates are comparable to the HCM and two-minute rule. However, the spread of over and under estimation is even for the 2010 model compared to over estimation from the two-minute rule and under estimation from the HCM method (Figure 2).

Next, a separate model was developed for the MJL lane configuration using 2013 data, to improve over the 2010 model estimates. A scatter diagram (Figure 3) between the major left volume and the queue length shows a wide spread of QLs and no definite trend observed visually.

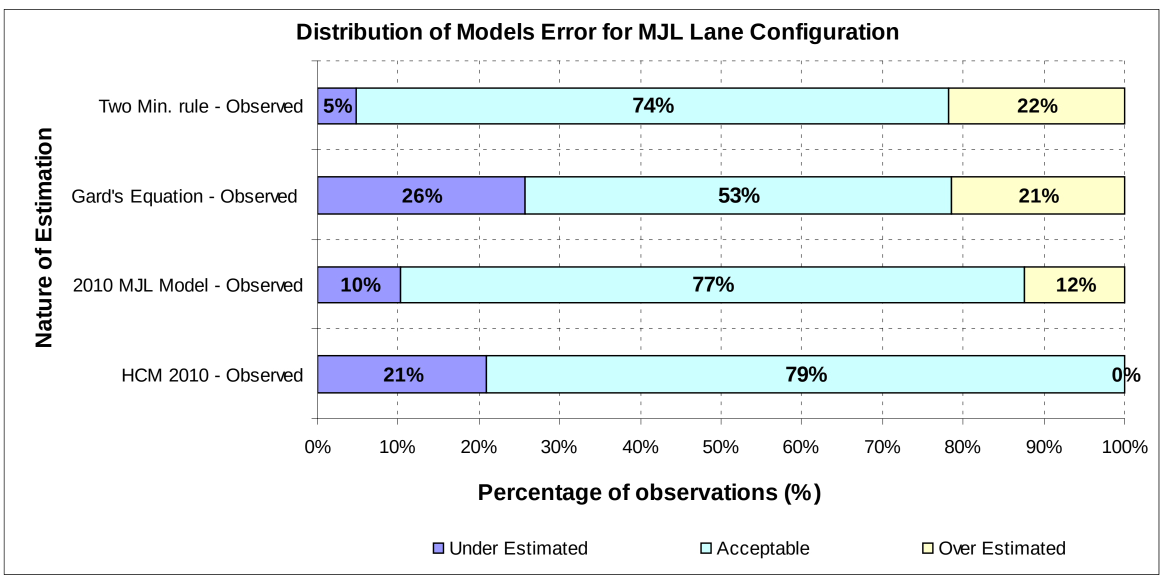

Figure 2. Comparison of 2010 MJL Model with Observed Queue Lengths

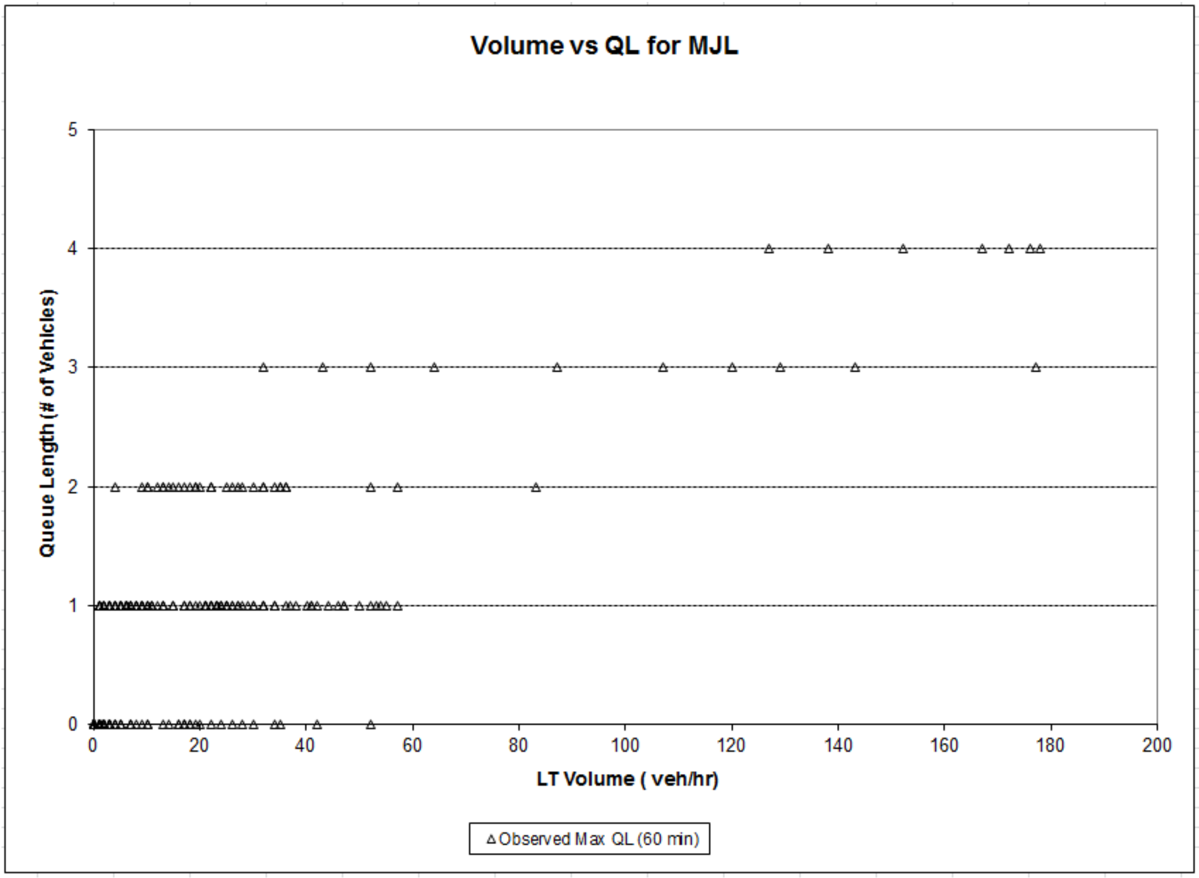

Figure 3. Observed Queue Lengths versus Observed Major Left Turn Volume

The observed queue length varied from a minimum of 1 vehicle to a maximum of 4 vehicles. Detailed statistical analysis is beyond the scope of this report. However, users may refer to the 2010 model development report for detailed model development analysis. After many iterations with the collected explanatory variables, only left turn volume (VOL), left turn conflicting volume (CONVOL), and combination of volumes explained the variability in QLs. However, the model only shows an R2 value of 0.55, which is less than the acceptable range of 0.60 to 0.80, generally considered for a good model. The lower value of R2 is due to less variability of QL with variation in left turn volume and conflicting volume. Next, the study made an attempt to see whether combining the 2010 and 2013 datasets brings more variability to the models. In fact, combination improves the model variability (R2 value) to 0.62. Table 2 shows the three models developed using data from both years.

Table 2. MJL Model Forms

Year Data Collected	MJL Model Form	R^2
2010	$QL = e^{(0.3925+0.0059*VOL+0.00104*CONVOL+0.49*Signal-0.81*LT)}$	67.0 (Percent of Deviation)
2013	QL = 0.69 + 0.007*VOL + 0.000071*CONVOL	0.55
2013 & 2010	QL = 0.70 + 0.004*VOL + 0.000078*CONVOL	0.62

Data validation used a part of 2013 data having variation in traffic and geometrical conditions. Comparison between the estimated and observed queue lengths showed that 80 percent of the 2010 model estimates are within the acceptable range. The model that uses the combined 2010 and 2013 data produces nearly 90 percent acceptable queue lengths. Figure 4 also shows the performance of other models. Both the two-minute rule and HCM 2010 methodologies are below 70 percent acceptable. In addition, the two-minute rule and Gard's equation over estimate QLs, whereas HCM 2010 is underestimating. The developed models other than the 2010 model over predict QLs but to a lesser extent than the two-minute rule and Gard's equation.

Though the 2013 model estimates are improved over the 2010 model, based on R2 value and nature of estimation (distribution of acceptable, under and over estimation) the 2010 model may best explain the MJL lane group QL.

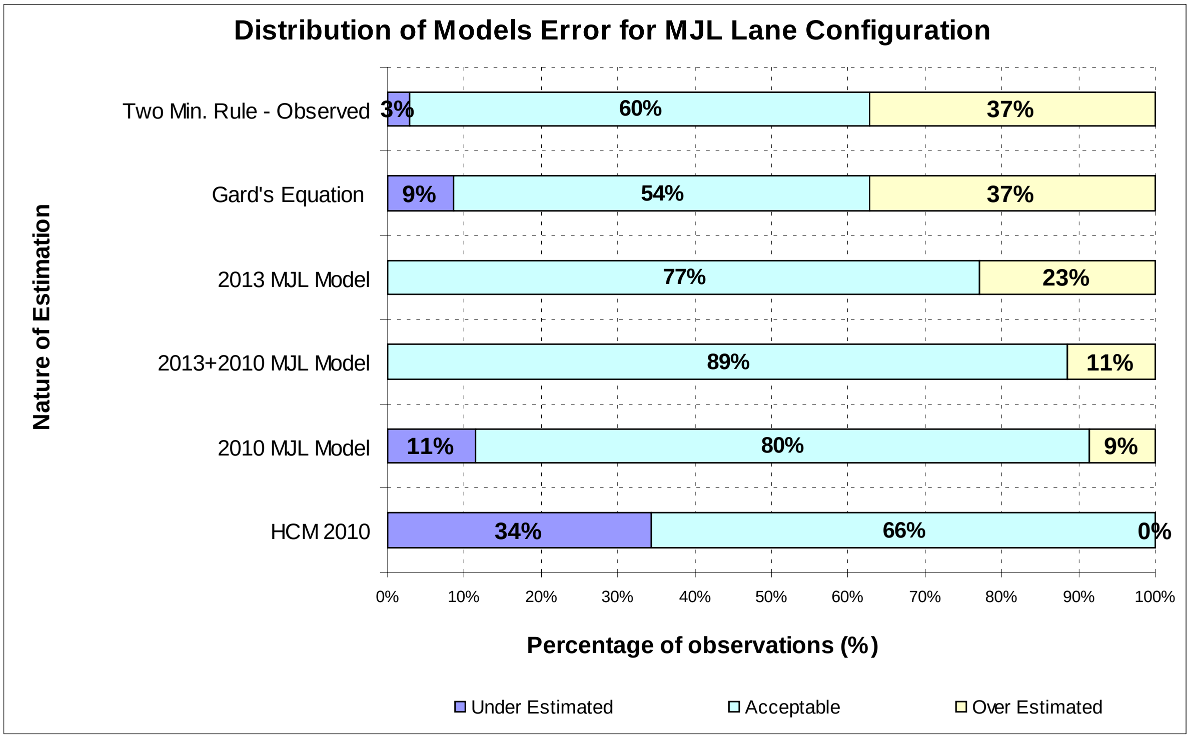

Figure 4. MJL Models Comparison

5 MNLTR Lane Group Analysis

When comparing the 2010 MNLTR model estimates with the observed QLs, around 78 percent of data (sample size of 357) is predicting acceptable QLs, which is 3 percent more than the two-minute rule estimates. However, the 2010 model underestimates more than it overestimates, as compared to the two-minute rule (Figure 5).

The best model form using 2013 data and combined years data does not yield good model fitness as the R2 value is less than 0.60 (Table 3). However, the validation data (sample size of 37) shows both the 2013 and combined year models predict nearly 90 percent acceptable QLs with even distribution of under and over estimation. The two-minute rule performs a little better than the 2010 model, but overestimates the QLs more than the 2010 model. The 2010 model evenly distributes the error in QL estimation (Figure 6).

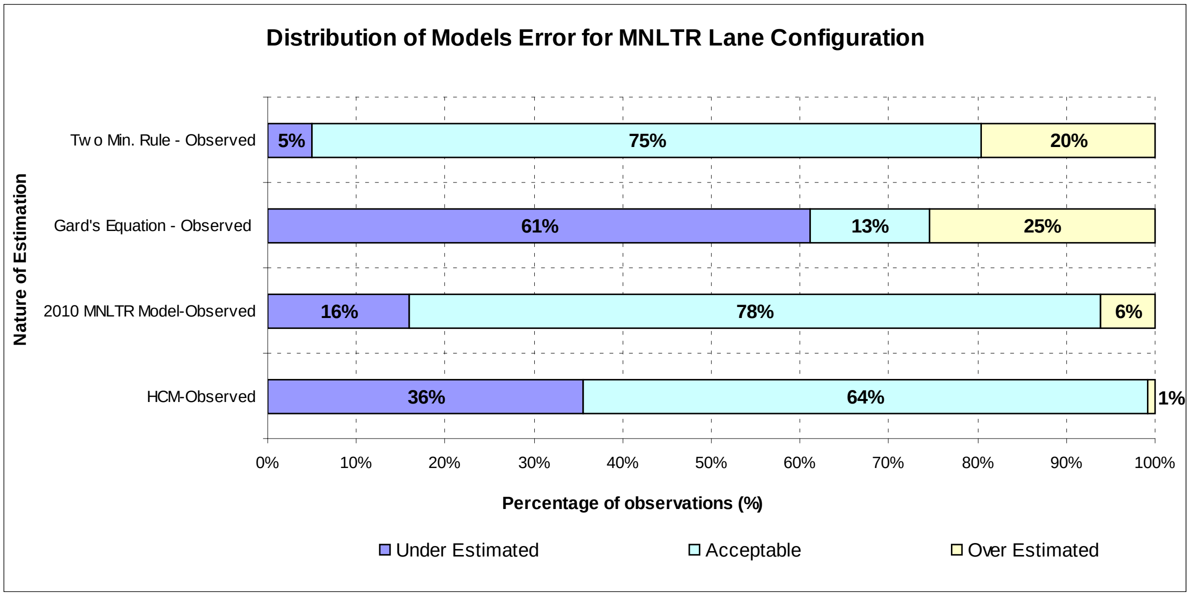

Figure 5. Comparison of 2010 MNLTR Model with Observed Queue Lengths

Though the 2013 model validation shows good results, based on the nature of estimation and model strength, the 2010 model seems the best for predicting minor shared left, through, and right lane configuration.

Table 3. MNLTR Model Forms

Year	MNLTR Model Form	R^2
2010	$QL= e^{(-0.7844+0.01636*VOL+0.0006*CONVOL-0.0000043*VOL*CONVOL)}$	71.6 (Percent of Deviation)
2013	$QL = 0.88 + 0.0253*VOL - 1.2225*(VOL / CONVOL)$	0.57
2013 & 2010	$QL = 0.65 + 0.0246*VOL + 0.000383*CONVOL - 0.00000414*VOL*CONVOL$	0.54

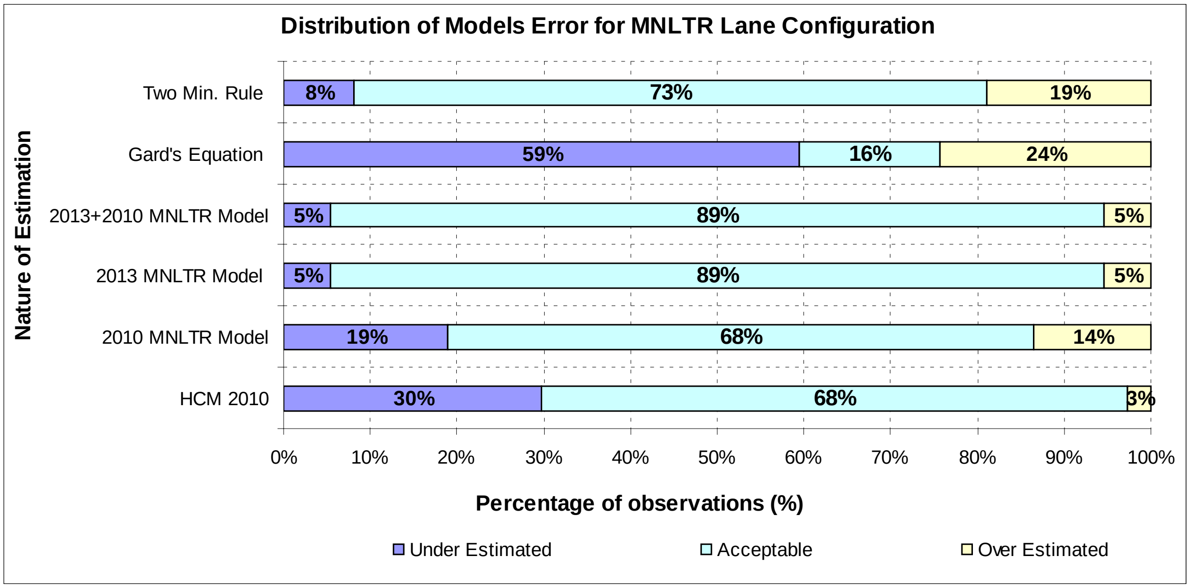

Figure 6. MNLTR Models Comparison

6 MNLR Lane Group Analysis

With an acceptable difference of one vehicle in queue length, 66 percent match with the 2010 model and 77 percent match with the two-minute rule. The HCM method matches 65 percent of the time. The results are shown in Figure 7. The 2010 model underestimates, but less when compared to the HCM methodology. However, the two-minute rule overestimates the QLs. The comparison shows some need to improve the 2010 model. The model form for 2013 and combined years data is shown in Table 4. The combined data model has a dummy variable "flared", which is zero if the minor street does not have a flared approach. However, the combined data model has a lower R2 value, less than 0.60.

Table 4. MNLR Model Forms

Year Data Collected	MNLR Model Form	R^2
2010	$QL = e^{(-0.6319+0.0173*VOL+0.00066*CONVOL-0.000007913*VOL*CONVOL)}$	69.3 (Percent of Deviation)
2013	QL = 0.8641+ 0.0133*VOL - 0.00038*CONVOL+0.0000179*(VOL* CONVOL)	0.64
2013 & 2010	QL = 1.274 + 0.0189*VOL -0.1610*(VOL / CONVOL) -0.4006* Flared	0.52

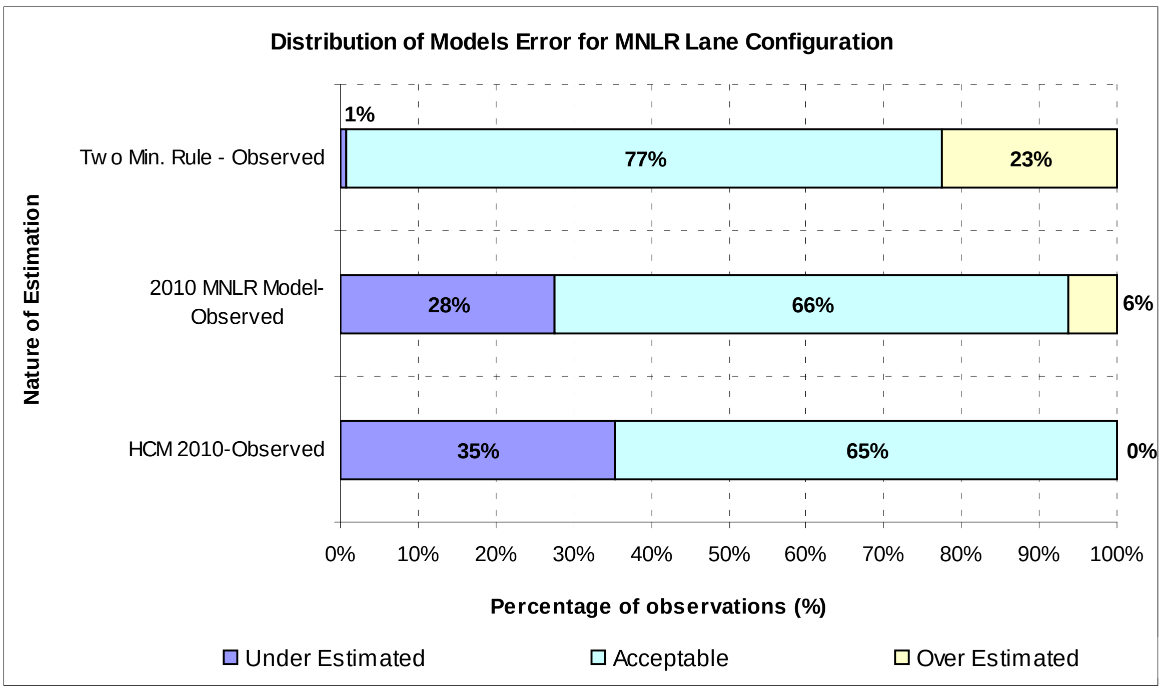

Figure 7. Comparison of 2010 MNLR Model with Observed Queue Lengths

When the models are validated using a sample size of 18, surprisingly the combined data model results in 90 percent acceptable QLs. Moreover, the 2010 and 2013 models have a 78 percent match, which is still 6 percent more than the two-minute rule. As with the other lane groups, the two-minute rule overestimates and the HCM method underestimates the QLs (Figure 8). Although the 2010 and 2013 models equally predict acceptable QLs, the 2013 model performs better in distributing the error difference; the

2010 model underestimates the QLs. Based on model strength, the 2010 model best describes the queue lengths for the three legged minor shared left and right turn lane group.

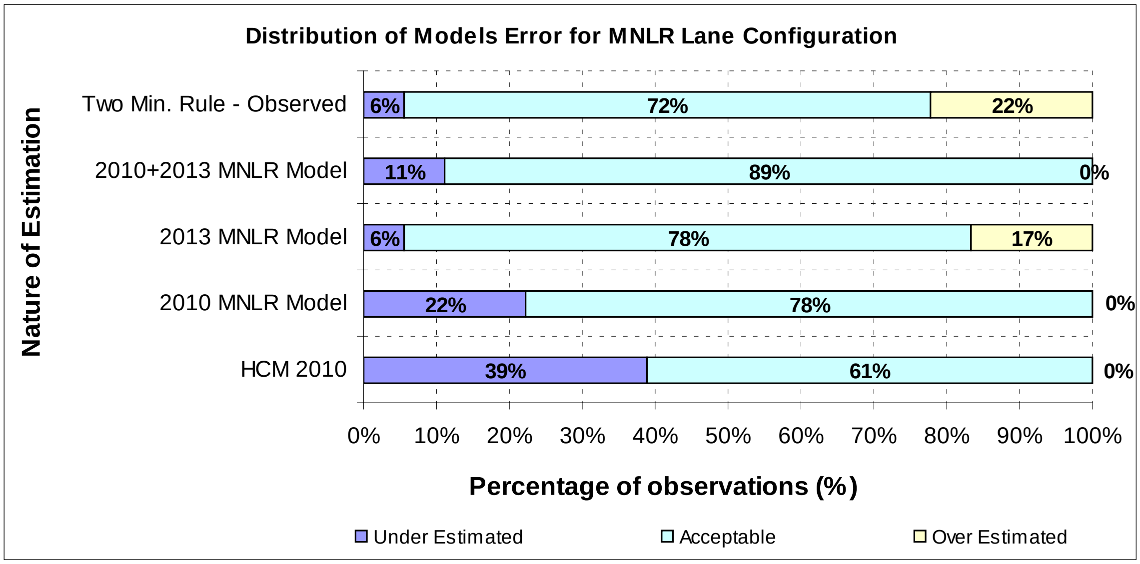

Figure 8. MNLR Models Comparison

7 MNL Lane Group Analysis

Both the two-minute rule and Gard's equation perform better than the 2010 MNL model. In addition, the 2010 model overestimates and the HCM methodology underestimates the QLs. Figure 9 clearly shows the 2010 model needs improvement. The model using 2013 and combined year data is listed in Table 5. Both 2013 and combined data models use volume and conflicting volume data to model QLs.

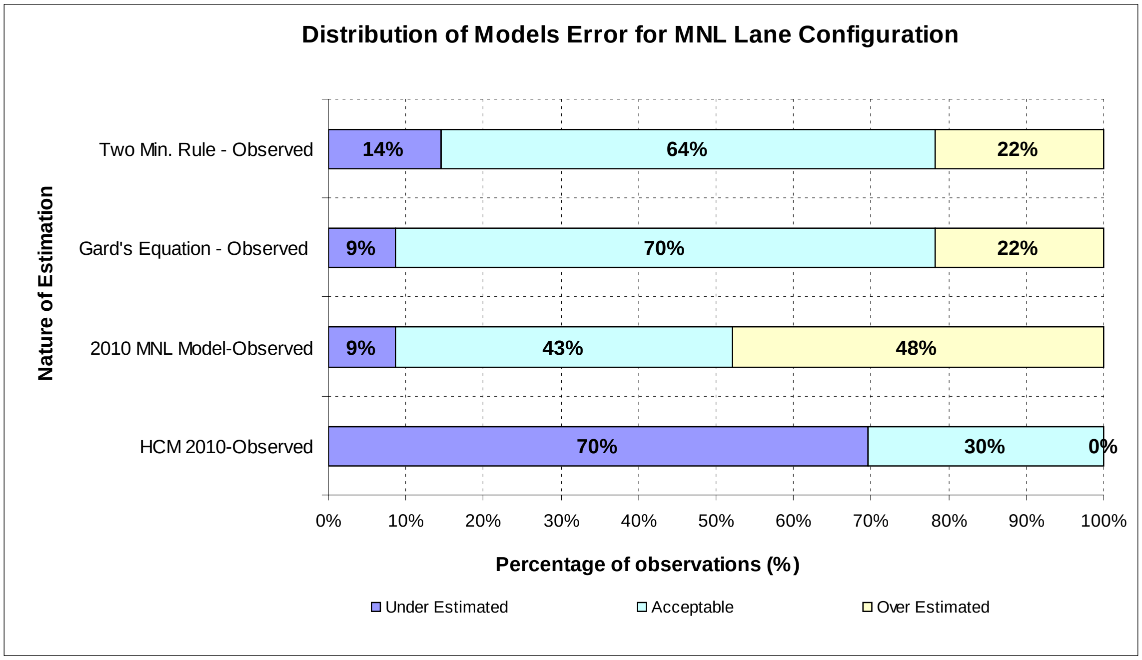

Figure 9. Comparison of 2010 MNL Model with Observed Queue Lengths

Figure 10 shows that the HCM methodology underestimates for most of the cases, and Gard's equation overestimates. Among the developed models, only the combined data model produces 53 percent acceptable QLs. Visually, the 2013 model produces slightly more acceptable queue lengths than the 2010 model. Error distribution is more even for the combined data model. The two-minute rule underestimates 61 percent of cases. Based on the model strength and distribution of errors compared to other models, the 2013 model best fits the MNL lane group QL estimation.

Table 5. MNL Model Forms

Year Data Collected	MNL Model Form	R^2
2010	$QL = e^{(1.7934-0.025*(CONVOL/VOL))}$	69.4 (Percent of Deviation)
2013	QL = 0.95+ 0.014*VOL +0.00074*CONVOL+3.01*(VOL/ CONVOL)	0.82
2013 & 2010	QL = 1.452+ 0.0217*VOL + 0.00126*CONVOL - 0.0147*(CONVOL / VOL)	0.53

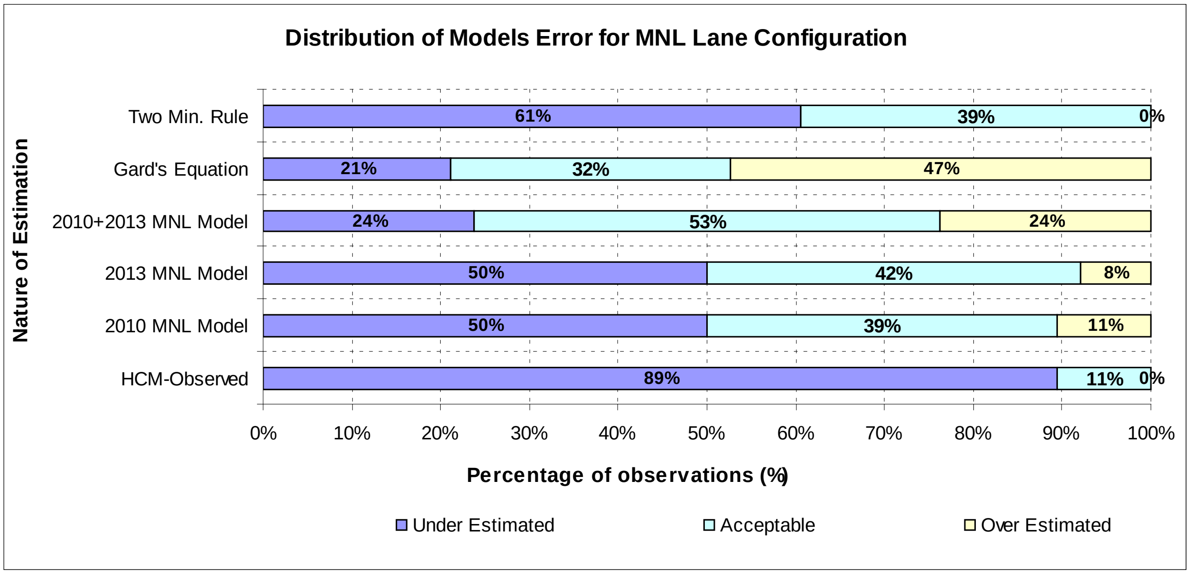

Figure 10. MNL Models Comparison

8 MNR Lane Group Analysis

The 2010 MNR model used only 18 data points and was not validated because of the very small sample size. Hence, the performance check for the 2010 model was not performed. Instead, a part of 2013 data (sample size of 44) was used to develop the model as shown in Table 6.

Table 6. MNR Model Forms

Year Data Collected	MNR Model Form	R^2
2010	QL= e $^{(0.2251+0.00005316*(VOL*CONVOL))}$	64.8 (Percent of Deviation)
2013	QL = 0.917+0.000047* VOL*CONVOL	0.37
2013 & 2010	QL = 0.865+ 0.0000534*VOL*CONVOL +0.2372*(VOL/CONVOL)	0.71

The differences between model and observed QLs are shown in Figure 11. Both the 2013 and combined year data models perform well compared to the 2010 model. The two-minute rule outperforms the 2010 model, but overestimates as compared to the 2013 model. Although the HCM methodology underestimates, it out-performs Gard's equation. Based on validation and model strength, the model based on combined year data may be used for MNR lane group queue length estimation.

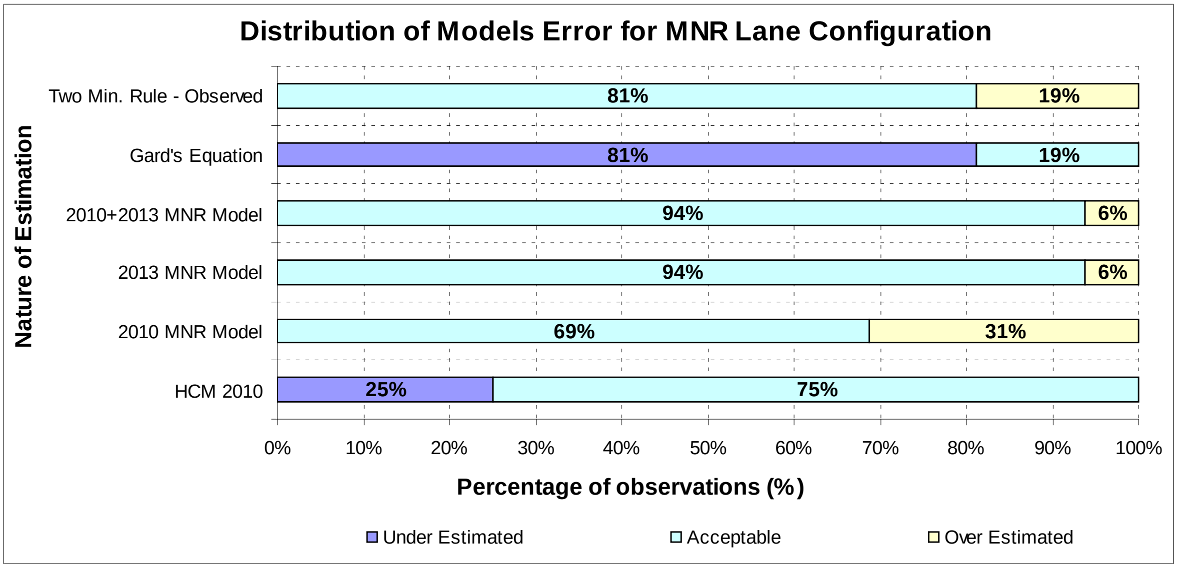

Figure 11. MNR Models Comparison

9 MNTR Lane Group Analysis

The minor shared through and right lane configuration is evaluated using a small sample size of 23. Only traffic volume on the lane group explains the variability in queue lengths. The best model, QL = 2.28 + 0.011 * VOL, has an R2 value of 0.61. The 2013 MNTR model was validated using 2010 data with a sample size of 13. The 2013 model produces 77 percent acceptable QLs compare to 69 percent from the two-minute rule (Figure 12). Both models are over predicting QLs, more so with the two-minute rule.

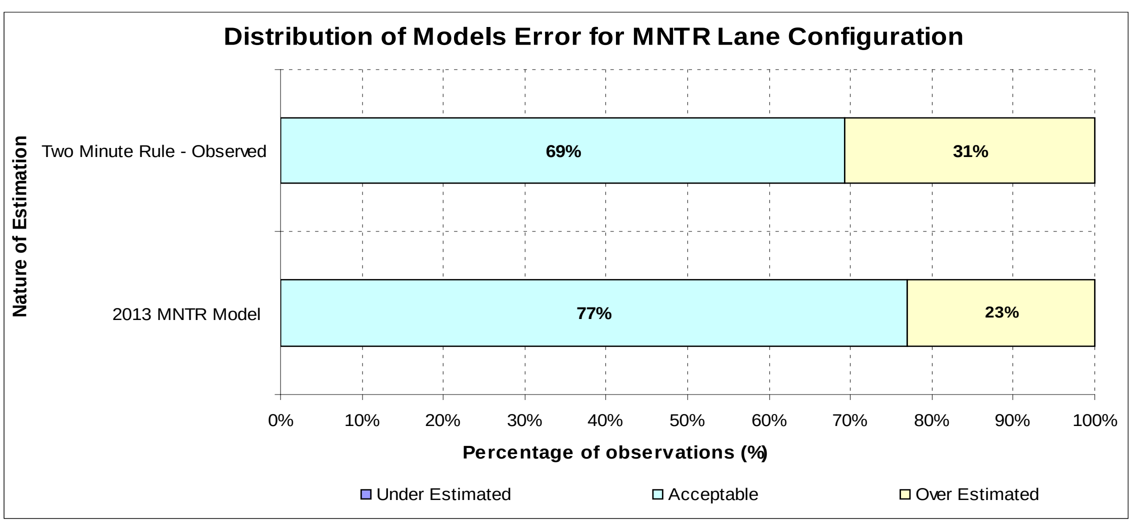

Figure 12. MNTR Models Comparison

10 Summary and Conclusions

The following table summarizes the developed models and applicable ranges for input data for each model:

Table 7. Summary of Queue Length Models

Lane Group	Model Equation & Ranges	R^2
MJL	$QL= e^{(0.3925+0.0059*VOL+0.00104*CONVOL+0.49*Signal-0.81*LT)}$ VOL = (0, 300] ; CONVOL = (0,2000] SIGNAL = 0 or 1 ; LT = 0 or 1	67 (Percent of Deviation)
MNLTR	$QL= e^{(-0.7844+0.01636*VOL+0.0006*CONVOL-0.0000043* VOL* CONVOL)}$ VOL = (0, 300] ; CONVOL = (0,3000]	72 (Percent of Deviation)
MNLR	$QL= e^{(-0.6319+0.0173*VOL+0.00066*CONVOL-0.000007913* VOL* CONVOL)}$ VOL = (0, 300] ; CONVOL = (0,3000]	69 (Percent of Deviation)
MNL	QL = 0.95+ 0.014*VOL +0.00074*CONVOL+3.01*(VOL/ CONVOL) VOL = (0, 300] ; CONVOL = (0,2000]	0.82
MNR	QL = 0.865+ 0.0000534*VOL*CONVOL +0.2372*(VOL/CONVOL) VOL = (0, 250] ; CONVOL = (0,1500]	0.71

VOL = Traffic volume on the subject approach in vehicles per hour;
CONVOL = Conflicting traffic volume as per the 2010 HCM methodology in vehicles per hour;
SIGNAL = Presence of upstream signal within ¼ mile of an intersection, applicable for major left turn only, 1 if there is a signal, otherwise 0;
LT = Presence of a separate left turn lane, applicable for major left turn only (1 if there is an exclusive left turn lane/median left turn lane/ two-way left turn lane, otherwise 0)

The developed models perform better than other models under different geography, traffic, and geometric characteristics. The 2013 data improves the predictability of the models. Although the study considered more explanatory variables, only volume and conflicting volume explain the variability in queue lengths. Based on the percentage variability in QL explained by the model, and the distribution of error differences between the predicted and observed QL, appropriate models were recommended for each lane group. Consistently, the two-minute rule overestimates and the HCM methodology underestimates queue lengths. Gard's equation estimates deviate from acceptable ranges for all lane group configurations. Moreover, the developed models distribute the error uniformly on both sides of the acceptable range. As always, data expansion has the potential to improve model predictability, especially for the minor shared through and left (MNTL), and minor shared through and right (MNTR) lane groups.

Appendix A - List of Study Intersections

TCM Site Number	No. of Legs	Region	County	Street Description	Mile Point	Location Description
19082	4	4	Crook	Main St/McKay Rd	2.14	Barnes Butte Rd @ Main St/McKay Rd
19084	4	4	Crook	S Fairview St	1.14	S Fairview St @ SE 5th St
19780	3	3	Jackson	PACIFIC HIGHWAY NO. 1 ROCK POINT FRONTAGE RD.	43.85	PACIFIC HIGHWAY NO. 1 ROCK POINT FRONTAGE RD. at Main Street (001CC, MP 44.23)
19791	3	3	Douglas	W Harvard Ave.		W Harvard Ave. @ W Maple St. vol only
19793	3	3	Douglas	NORTH UMPQUA HIGHWAY NO. 138	-0.75	OR138(W Harvard Ave.) @ W Corey Ct. vol only
19794	4	3	Douglas	W Harvard Ave.		W Harvard Ave. @ Harrison St. - vol only 6-9A & 3-6P
19842	4	3	Jackson	Talent Ave	1	Talent Ave (Rd 523, MP1.00) @ Creel Rd (Rd 8381, MP 0.23)
19844	3	3	Jackson	ROGUE VALLEY HIGHWAY NO. 63	10.86	Rogue Valley Hwy No. 63 (OR99) at N Rose Street (Rd 3816, MP 0.00)
38422	4	3	Douglas	COOS BAY-ROSEBURG HIGHWAY NO. 35	71.73	COOS BAY-ROSEBURG HIGHWAY NO. 35 @ Brockway Rd
38488	3	3	Curry	OREGON COAST HIGHWAY NO. 9	356.11	OREGON COAST HIGHWAY NO. 9 (US101) at Ransom Ave
4142011	3	2	Clatsop	LOWER COLUMBIA RIVER HIGHWAY NO. 92	94.6	US30 @ Tongue Point Rd.(old US30)
8032012	3	3	Curry	OREGON COAST HIGHWAY NO. 9	358.94	US101 @ Raymond Lane 4hr count 2-6P
8072012	3	3	Curry	OREGON COAST HIGHWAY NO. 9	358.45	US101 @ Court St. 4 hr count 2-6P Volume only
8092012	3	3	Curry	OREGON COAST HIGHWAY NO. 9	358.97	US101 @ Kings Way 4hr count 2-6P volume ony
9142011	4	4	Deschutes	MCKENZIE HIGHWAY NO. 15	110.15	OR126 (SW Highland Ave) @ 35th St
9172011	3	4	Deschutes	O'NEIL HIGHWAY NO. 370	2.11	OR370 @ NE 25th St.
9192011	3	4	Deschutes	O'NEIL HIGHWAY NO. 370	3.29	OR370 @ NE 41st St.
10032012	3	3	Douglas	COOS BAY-ROSEBURG HIGHWAY NO. 35	75.42	Coos Bay Roseburg Hwy(OR99) @ SW Landers Ave.
10112012	3	3	Douglas	NW Edenbower Blvd.		NW Edenbower Blvd. @ NW Broad St.
10282011	4	3	Douglas	UMPQUA HIGHWAY NO. 45	0.64	OR38 @ Winchester Ave. & River Front Way
15012012	3	3	Jackson	E Main St.		E Main St. @ Tolman Creek Rd.
15062012	3	3	Jackson	Wagner Creek Rd.		Wagner Creek Rd. @ Foss Rd. 3 hr cout 3-6p
15072012	3	3	Jackson	Wagner Creek Rd.		Wagner Creek Rd. @ W Wagner St. 3 hr count 3-6P

TCM Site Number	No. of Legs	Region	County	Street Description	Mile Point	Location Description
15082011	4	3	Jackson	Ashland St.		Ashland St. @ Normal Ave
15092011	3	3	Jackson	JACKSONVILLE HIGHWAY NO. 272	34.87	OR238(Hanley Rd.) @ W Main St.)
15112011	4	3	Jackson	GREEN SPRINGS HIGHWAY NO. 21	0.88	OR66(Ashland St. @ Clay St. & driveway(south leg)
15132012	4	3	Jackson	Front St.		Front St. @ Main st. 3 hr count 3-6P
16012012	4	4	Jefferson	MADRAS-PRINEVILLE HIGHWAY NO. 360	1.15	US26 @ SW Dover Lane
16022012	3	4	Jefferson	THE DALLES-CALIFORNIA HIGHWAY NO. 4	96.48	US97 @ SW Fairgrounds Rd.
20132011	3	2	Lane	N Delta Hwy		North Delta Rd. @ N Stapp Dr.
20172011	3	2	Lane	River Rd.	10.33	River Rd. @ Corliss lane
21062012	3	2	Lincoln	Toledo Frontage Rd (US20 Bus)	7.46	Toledo Frontage Rd (US20 Bus) @ East Slope Rd
21072012	3	2	Lincoln	Toledo Frontage Rd (US20 Bus0	8.21	Toledo Frontage Rd (US20 Bus) @ NE Sturdevant Rd
23012012	4	5	Malheur	OLDS FERRY-ONTARIO HIGHWAY NO. 455	25.75	Yturri Beltline @ NW Washington Ave. site 4801 - south leg
25012010	4	5	Morrow	COLUMBIA RIVER HIGHWAY NO. 2 PORT OF MORROW CONN. NO. 3	165.54	I-84 e/b ramps @ Laurel Lane
25022010	4	5	Morrow	COLUMBIA RIVER HIGHWAY NO. 2 PORT OF MORROW CONN. NO. 5	166.1	I-84 w/b on/off ramps @ Laurel Lane
27122011	3	2	Polk	N Main St.		N Main St. @ Ellis St.
7012011	3	4	Crook	OR370	4.99	OR370 @ Lone PIne Rd.