What Drives Single Occupant Traveler Decisions in HOT Lanes? An Investigation Using Archived Traffic and Tolling Data from the MnPASS Express Lanes

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ABSTRACT

High-occupancy toll (HOT) lanes are in operation, under construction, and planned for in several major metropolitan areas. The premise behind HOT lanes is to allow single occupant vehicles (SOVs) to access high occupancy vehicle (HOV) lanes (and, a higher level of service) if they are willing to pay a toll. To maintain a high level of service in the HOT lanes, the toll rate is set dynamically to restrict the number of SOVs which access the facility as it nears capacity. Thus, HOT facilities provide operators of transportation systems with a new operations tool: pricing. In order to effectively use pricing, it is critical to understand driver behavior when faced with a set of traffic conditions and toll levels. This paper presents the results of an empirical investigation into the relationship between toll rate, traffic conditions, and SOV driver behavior, based on data from the dynamically-tolled I-394 HOT facility in Minneapolis, Minnesota. Analysis of the empirical data indicated that a large percentage of SOV drivers use the HOT lanes at different, yet predictable rates throughout the AM peak period, even when there is no clear travel time advantage. After accounting for these “regular” users, the remaining SOV drivers utilize the HOT lanes at greater rates when the cost per hour of commute time saved is lowest. A model was developed that incorporates both of these findings, predicting HOT lane usage rates based on time savings, time of day, and toll rates with an R^2 value of 0.684.

Key words: Intelligent transportation systems, HOT, dynamic tolling

INTRODUCTION

High occupancy toll (HOT) lanes are a form of managed lanes that offer free or reduced-toll travel to high occupancy vehicles (HOVs), while allowing single occupant vehicles (SOVs) that pay a toll (1). Some HOT lanes employ dynamic pricing strategies to control congestion and maintain high speeds, by changing toll rates in response to congestion. These HOT facilities are an example of the emerging approach known as "active traffic management" (ATM), in which infrastructure providers seek to manage recurrent and non-recurrent congestion based on real time traffic conditions (2). Currently, HOT lanes exist in several U.S. cities, and more are under construction or planned.

The HOT lanes concept relies on the assumption that SOVs will be discouraged from entering the HOT lanes as toll rates increase, thus preventing the HOT lanes from becoming congested. Most willingness-to-pay research has focused either on revealed preference (RP) surveys (3), or has investigated the median cost per hour of commute time saved (4). Little research has been conducted to analyze and model drivers' responses to minute-to-minute changes in toll rates and traffic conditions using empirical data from an operational HOT lane system. This paper attempts to understand and model the impact of toll rates and traffic conditions on single occupant driver behavior in a HOT lane system, through analysis of data from an operating HOT lane facility in Minneapolis, Minnesota. This will be necessary in order to make maximum use of this ATM strategy – allowing operators to fully understand the impact of toll increases on traffic assignment.

HOT lane usage is measured from a combination of toll transaction records and detector data from the I-394 MnPASS Express Lane system. The study period was the AM peak period between November 7, 2006, and March 31, 2008, along the 2.7 mile barrier-separated reversible section of I-394 near downtown Minneapolis. The study ignores the possibility of SOVs using the system illegally, based on the very low 3% non-compliance rate found on the study section in a 2006 study (5).

MNPASS FACILITY

The I-394 MnPASS is an 11-mile HOT lane facility in Minneapolis, Minnesota operated by the Minnesota Department of Transportation (MnDOT). The facility, which has been in operation since May 2005, is one of the few HOT lanes that dynamically adjusts toll rates in response to traffic conditions. Between Central Avenue and Trunk Highway 100 (TH 100), the HOT lanes are former HOV lanes in both directions, separated from general purpose (GP) lanes over 8 miles by double white lines. The double striped lanes, often referred to as "diamond" lanes, operate Monday through Friday, from 6 AM to 10 AM in the eastbound direction, and 2 PM to 7 PM in the westbound direction. From TH 100 to I-94, the facility operates as a two lane reversible facility 2.7 miles in length. The reversible HOT lanes are barrier separated from the GP lanes. The reversible section is operational at all times, including weekends, except when the lanes' directions are being switched. The HOT lanes are operated in the eastbound direction from 6 AM to 1 PM, and in the westbound direction from 2 PM to 5 AM. A map of the facility is provided in Figure 1 (6).

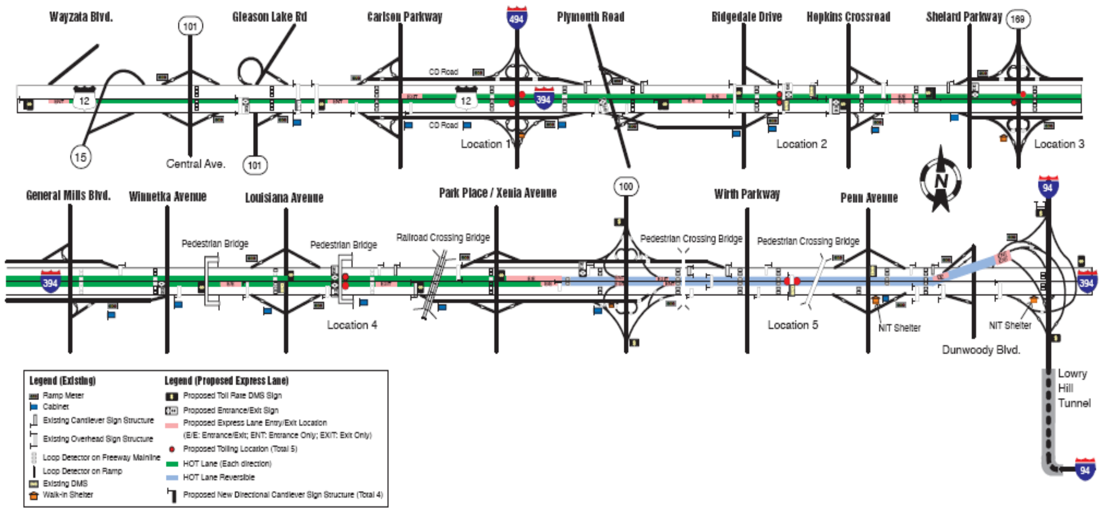

FIGURE 1 I-394 MnPASS HOT Lanes (6).

Tolls for SOVs are collected electronically at five locations. SOVs using the HOT lanes must be equipped with MnPASS transponders. Transponders can be leased for $1.50 per month. The diamond and reversible sections have separate toll rates. Rates are automatically adjusted every three minutes in order to maintain high speeds in the HOT lanes. The total toll for a vehicle using the entire system ranges between $0.50 and $8.00 per trip.

ANALYSIS

To focus on the periods of highest congestion and toll rates (when SOVs are most likely motivated to utilize HOT lanes), the study focused on the reversible section during the AM peak period from 6 AM to 10 AM, Monday through Friday. Data was obtained from MnDOT covering the period from November 2006 to March 2008 at three-minute intervals. The following data was collected from MnDOT:

- Toll rates and their start times.
- Individual toll transactions by vehicle, time-stamped and identified by each electronic toll reader passed.
- Detector data from five detectors in the HOT lanes and 5 detectors in the GP lanes, with speeds, volumes, and occupancies recorded at three-minute intervals. Detector data was validated using data quality standards developed by the Texas Transportation Institute (7).

This data was used to determine the cost per hour of travel time saved by employing the following set of equations shown in Table 1.

TABLE 1 Equations Used in Calculating Cost per Hour Travel Time Saved

HOT Lane Speed (speed limit = 65 mi/hr)	GP Lane Speed (speed limit = 55 mi/hr)	Equation Used
≥ 65 mi/hr	≥ 55 mi/hr	No advantage, value is null
≥ 65 mi/hr	< 55 mi/hr	$c = \dfrac{T}{\dfrac{D}{S_{GP}} - \dfrac{D}{L_{HOT}}}$
< 65 mi/hr	≥ 55 mi/hr	No advantage, value is null
< 65 mi/hr	< 55 mi/hr	$c = \dfrac{T}{\dfrac{D}{S_{GP}} - \dfrac{D}{S_{HOT}}}$

Where

c = cost per hour of travel time saved ($/hr)
T = toll rate ($)
D = distance of the highway segment (mi), in this case 2.7 miles
S = speed of the HOT or GP lanes (mi/hr)
L = speed limit of the HOT or GP lanes, 65 and 55 respectively (mi/hr)

RESULTS

When one first examines the data, it appears that the cost per hour of travel time saved has little influence on SOV behavior. As seen in Figure 2, which summarizes the data over all time intervals in the AM peak, regardless of the cost per hour of travel time saved, roughly 14-15% of SOVs choose to travel in the HOT lanes.

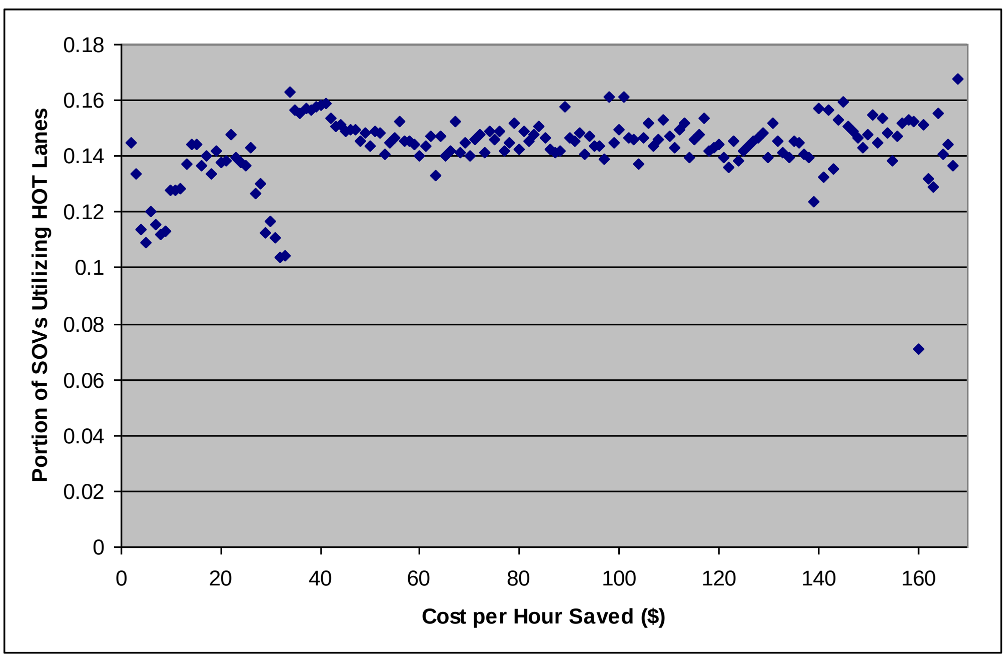

FIGURE 2 Average portion of SOVs utilizing HOT lanes vs. cost per hour saved.

However, when plotting the time series of the percentage of SOVs utilizing the HOT lanes during the AM peak period, one will notice a clear fluctuation in HOT lane utilization, regardless of traffic conditions or toll rate. For example, Figure 3 shows the average HOT lane utilization when GP speeds are above 55 miles per hour, the speed limit on this facility. Even in these conditions, with very little apparent incentive to utilize the HOT lanes, drivers are almost six times more likely to use the HOT lanes at mid-peak than during early peak.

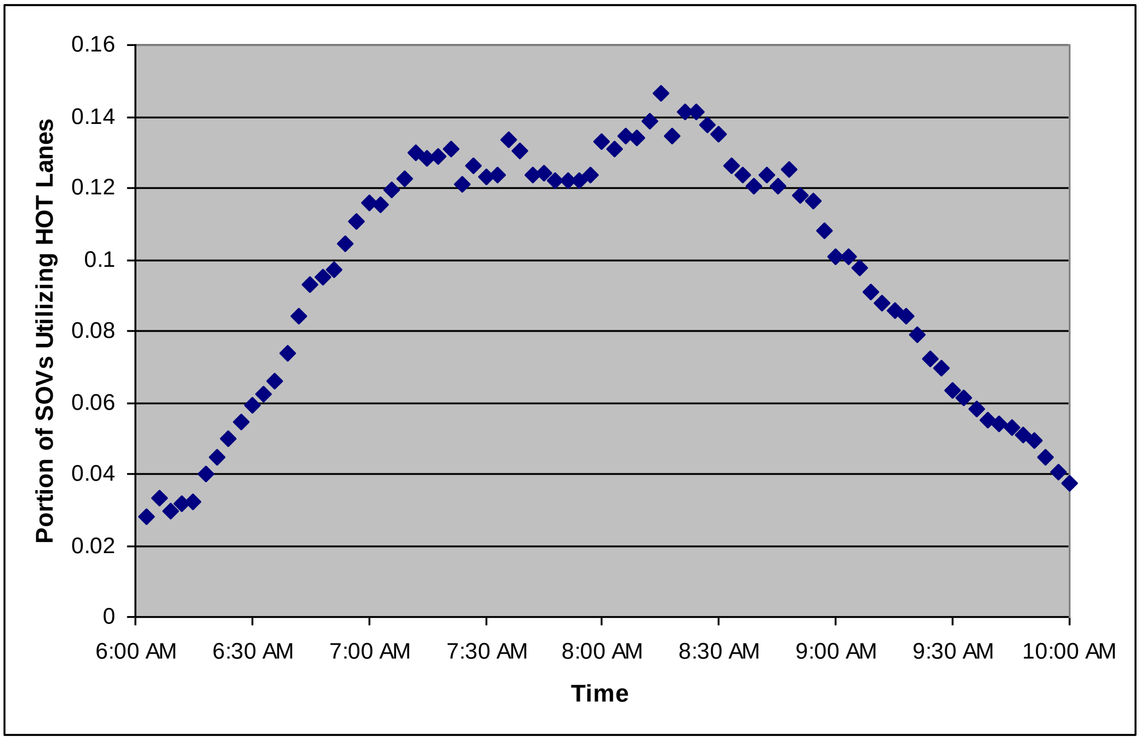

FIGURE 3 Time series of the average portion of SOVs utilizing HOT lanes, when GP speeds are greater than 55 miles per hour.

There are several possible explanations for this phenomenon. First, because MnDOT was careful not to over-market the MnPASS transponders (8), it is likely that most of the MnPASS users are drivers who routinely experience heavier than average congestion. It is possible that a greater percentage of drivers during the mid-peak period have transponders, and thus explains their greater proportion in the HOT lanes. Small et al. (9) have suggested that travel time reliability is also an important factor in driver behavior. In their analysis of the I-15 dynamically-priced HOT lanes in San Diego, Brownstone et al. assumed travel time reliability to be a major decision factor for drivers (4). Because the GP lane speeds are less reliable during mid-peak, drivers may be using the HOT lanes as insurance against congestion, regardless of the evidence of any congestion upstream.

Assuming that the drivers who use the HOT lanes even when there is no apparent benefit in travel time are insensitive to price, these drivers can be considered to be "every day" HOT lane users. In other words, these SOV users will choose the HOT lanes largely for their reliability as opposed to an improvement in current conditions. Therefore, it is reasonable to "remove" these SOVs from the data in an attempt to model behavior for the set of drivers that are sensitive to costs associated with real-time travel time savings.

By removing the average portion of "every day" drivers from each individual data record based on its time-of-day, one can directly consider drivers who are more sensitive to travel time savings and conditions. Figure 4 shows the average portion of SOVs using the HOT lanes at various prices for travel time savings, with the "every day" drivers removed from the data. The relationship here is much clearer, as SOV drivers use the HOT lanes at greater rates when the relative cost is lowest.

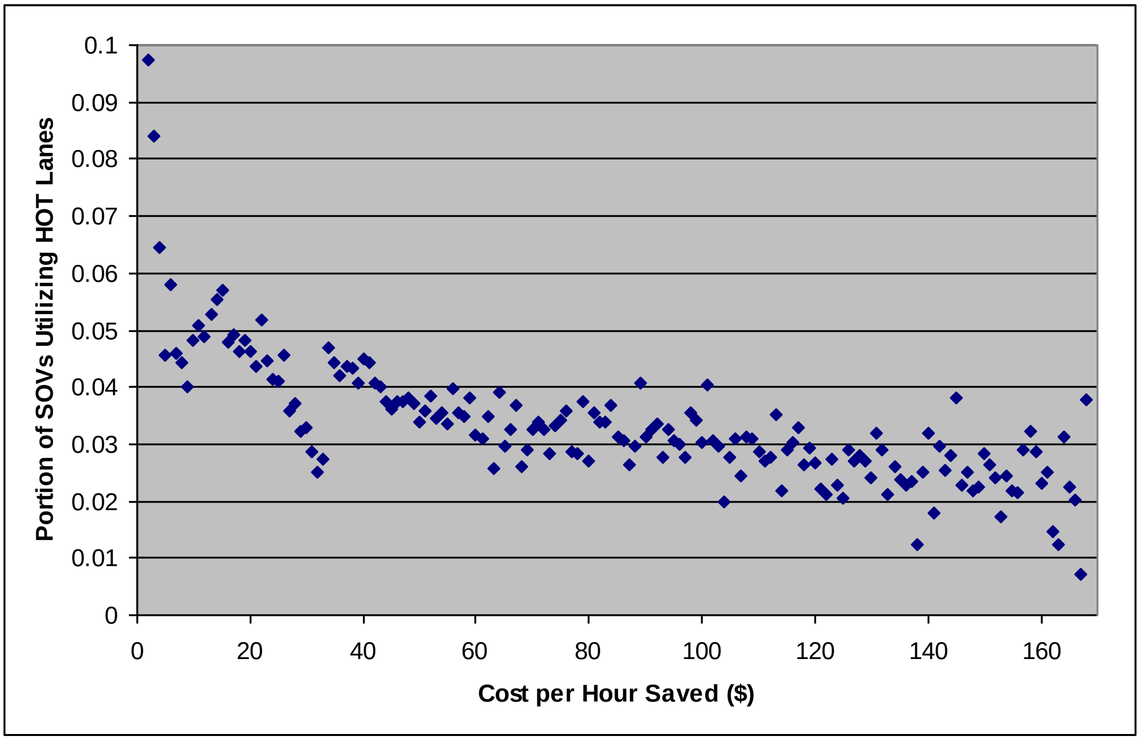

FIGURE 4 Average portion of SOVs utilizing HOT lanes vs. cost per hour saved, after removing the "every day" HOT lane SOVs.

The research team chose to model the relationship illustrated in Figure 4, with an exponential model, as shown below.

$$P(c) = \alpha \ln(c) + \beta$$

Where *P(c)* is the average percentage of SOVs using the HOT lanes at the cost per hour of travel time saved *c*. Based on a regression of average HOT lane utilizations, values of α and β were found to be -0.0107 and 0.078 respectively. The model had an R^2 value of 0.7265.

Development of SOV HOT Lane Model
Based on the results presented in the previous section, the research team is proposing the following two component model of SOV behavior to account for the "every day" and price sensitive drivers.

$$U(t,c) = E(t) + P(c)$$

Where

$U(t,c)$ = Percentage of SOVs using the HOT lanes in time interval t at cost per hour of travel time saved c

$E(t)$ = Average percentage of SOVs using the HOT lanes in time interval t when speed in the GP lanes is above 55 mi/hr (speed limit)

$P(c)$ = Average percentage of SOVs using the HOT lanes at the cost per hour of travel time saved c

When the model was applied to the entire MnPass data set, the multi-component model has an R^2 value of 0.684. Figure 5 provides an example of the model as applied to a typical day.

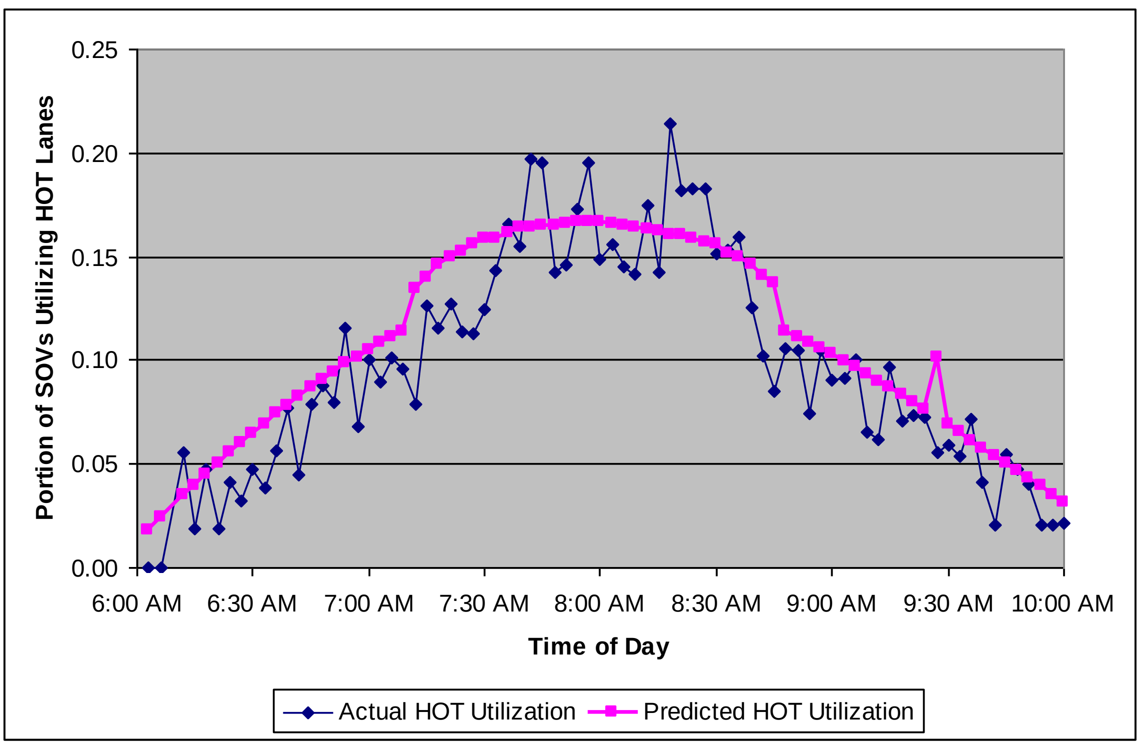

FIGURE 5 Comparison of predicted and actual HOT lane utilization on March 28, 2008.

As the reader will note, the performance of the multi-component model is driven largely by the everyday user component, *E(t)*. When only the historical average percentage of SOVs using HOT, under any traffic conditions (i.e. *E(t)* without the restriction of GP lanes operating at 55 mph or higher) is used to model *U*, an R^2 value of 0.675 results. Thus, the pricing has negligible influence. This is a very important finding in terms of future operation of HOT facilities. In this case, it is clear that the current pricing structure and population of eligible SOVs result in a situation where pricing is ineffective in preventing SOVs from using the HOT lanes when deemed necessary.

CONCLUSIONS

Based on an analysis of the data from the MnPASS HOT facility, SOVs utilize the HOT lanes at different rates throughout the AM peak period, even when GP lanes are operating above the speed limit and there is no strong advantage to using the HOT lanes. These drivers appear to place greater value on protection from possible future congestion than immediately visible travel time savings. Assuming these drivers use the HOT lanes as an "insurance" against unanticipated congestion, this portion of vehicles is can be ignored in the analysis of vehicles that are influenced by cost per hour of commute time saved. The remaining drivers show a clear relationship between value of travel time and usage of the HOT lanes. Accounting for both groups of drivers separately, then adding together their combined usage rates, creates a model which may be useful as DOTs attempt to predict traffic assignment in HOT facilities.

An equally important finding of this research, if not more important, is that much of the variation in HOT lane usage may be explained not by cost or current conditions, but by expected traffic conditions. This is likely because most drivers do not typically have access to real-time travel time estimates, and thus must estimate the traffic conditions based on a combination of sporadic traffic reports, HOT lane toll rates, and historical congestion at that particular time of day. The HOT lanes experience an increase in usage during the middle of the AM peak period, even when there is little immediately apparent advantage to using HOT lanes. There are two possible explanations. First, drivers may be anticipating greater congestion during the middle of the peak period based on congestion in the past, and may be using HOT lanes to avoid potential rather than actual congestion. Second, there may be a greater proportion of drivers with HOT lane transponders during this period, as drivers using the facility during this time period are the most likely to encounter congestion, and therefore have the greatest incentive to participate in the MnPASS program.

Previous analysis of HOT lane usage assumed drivers had knowledge only of historic average travel times, not real time traffic conditions (4). As traveler information becomes more widely available through 511, IntelliDrive applications, smartphones, and in-vehicle navigation systems, drivers will be able to make more informed decisions. As these devices and applications become more widely available, and as travel time data become more accurate and sophisticated, drivers may begin to make decisions based more on real-time conditions rather than perceived conditions or past experiences. This indicates the need for on-going analysis of HOT usage data to allow for most effective operation of the facilities.

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