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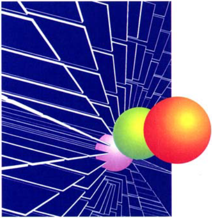
RDT 00-009

Evaluation of Undersealing and Diamond Grinding Rehabilitation

RI 86-002
RI96-017



August, 2000

RDT Report

RI86-002 and RI96-017

Evaluation of Undersealing and Diamond Grinding Rehabilitation

MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

BY: John Donahue, *Research and Development Engineer*; Stowe Johnson, *Research and Development Assistant*; and Eric Burks, *Senior Research and Development Technician*

JEFFERSON CITY, MISSOURI
DATE SUBMITTED: August, 2000

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Undersealing and Diamond Grinding Rehabilitation		5. Report Date May 2000
		6. Performing Organization Code
7. Author(s) John Donahue, Stowe Johnson, and Eric Burks		8. Performing Organization Report No.
9. Performing Organization Name and Address Missouri Department of Transportation Research, Development and Technology P. O. Box 270-Jefferson City, MO 65102		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Missouri Department of Transportation Research, Development and Technology P. O. Box 270-Jefferson City, MO 65102		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code

15. Supplementary Notes
The investigation was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration.

16. Abstract
This investigation evaluated the performance of three different segments of pavement in Missouri that underwent undersealing and diamond grinding rehabilitation. Undersealing was used to fill in voids underneath PCCP slabs and help stabilize them. Diamond grinding was then used to remove faulting at joints and restore smoothness to the pavement sections. The test sections were located on I-44 in Greene County, Rt. 171 in Jasper County, and I-35 in Harrison County.

17. Key Words	18. Distribution Statement
Undersealing, Diamond Grinding	No restrictions. This document is available to the public through National Technical Information Center, Springfield, Virginia 22161

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (06/98)

EXECUTIVE SUMMARY

This report combines the work of research investigations RI86-002, RI96-017, and the Long Term Pavement Performance (LTPP)-related RI91-001. The first investigation examined a section of pavement on Rt. 171 in Jasper County, which had its slabs undersealed and faulted joints diamond ground in 1985. The second investigation studied an eleven mile piece of pavement on I-44 in western Greene County, which had undersealing and diamond grinding performed in 1996. The last investigation looked at two test sections on an LTPP site on southbound I-35 in Harrison County.

The primary objective of these investigations was to measure the performance of the combination of undersealing and diamond grinding (U/D) on Portland cement concrete pavement (PCCP) and determine its reliability as a standard concrete pavement restoration (CPR) technique.

The secondary objective was to determine the causes of early failures, if they occurred.

Different investigations of U/D projects produced uneven results. The Route 171 project performed well, probably beyond anyone's original expectations. After fifteen years of service there is currently no justification to consider rehabilitating the pavement in the near future. The I-44 projects, which had probably been constructed past their time of optimum usefulness, appeared to have only momentarily halted the pavements' rate of deterioration. The prevalent faulting distress reappeared within a year after they were completed. The I-35 minimum and maximum restoration test sections yielded better results than the I-44 ones. They also returned to a rehabilitation-triggering level of roughness, but at a slower speed of deterioration and provided an acceptable level of service for approximately four to five years.

The general conclusion of the investigations is that U/D can be an effective CPR technique under the right conditions. PCC pavements that meet certain criteria, pending an appropriate evaluation, may be eligible for U/D restoration without additional rehabilitation.

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INTRODUCTION

The Missouri Department of Transportation (MODOT) has taken a strong interest in the rehabilitation of its aging Portland cement concrete pavements (PCCP). Many of these pavements, built during the late 1950s and early 1960s, have exceeded their original design lives and have endured truck loadings far in excess of what was originally conceived. These pavements have also suffered from lack of drainage, since in many cases older PCCPs were constructed on dense graded granular bases enveloped by impervious soils. Water became trapped in these bases and over many years their fines pumped out through the joints, which led to loss of support and subsequent faulting and cracking.

There is a great need to start upgrading these pavements, however, budget realities constrain wholesale rebuilding. Rather, as pavements wait their turn for major fiscal investments, many of them require short term solutions to bridge the gap till reconstruction. These short term solutions or rehabilitation strategies must be justified economically, but must also restore and maintain a reasonable service level over the duration.

One of these short term solutions is a combination of undersealing and diamond grinding (U/D). Undersealing fills in voids and restores support under slabs, while diamond grinding restores ride on the surface.

Three separate MODOT investigations were conducted to study the performance of this rehabilitation strategy. The first investigated Project 7-P-71-329, completed in 1985 on Rt. 171 north of Joplin in Jasper County. The second studied two adjacent pavements sections on I-44 west of Springfield in Greene County, which were rehabbed in 1996 under Projects J8I630 and J8I0631. The third was not another independent MoDOT investigation, but instead was part of the Missouri Long Term Pavement Performance (LTPP) program. Data was used from two test sections at a Specific Pavement Study (SPS) site on I-35 in Harrison County. Because of their common theme, the results of these independent investigations were combined into this single report.

OBJECTIVES

The primary objective of these investigations was to measure the performance of the combination of PCCP undersealing and diamond grinding and determine its reliability as a standard concrete pavement restoration (CPR) technique.

The secondary objective was to determine the causes of early failures, if they occurred.

DISCUSSION OF PRESENT CONDITIONS

To better understand the degrees of faulting and their impact on pavements the American Concrete Pavement Association (ACPA) developed the index shown in Table 1 *(1)*. It is evident from the index that highway users will begin to notice faulting at 3/16".

Average Fault	Faulting Index	Comments
1/32"	5	No roughness
1/16"	10	Minor faulting
3/32"	15	Trigger grinding needed
1/8"	20	Expedite project
5/32"	25	
3/16"	30	Discomfort begins
7/32"	35	
1/4"	40	Immediate attention needed

TABLE 1 ACPA Faulting Index

ERES Conultants, Inc. completed a study in 1998 *(2)* in which they surveyed over 300 PCCP segments in North America and used the data to develop a cracking model based on cumulative ESALs. From this fatigue model, a relationship between slab thickness and concrete strength was derived in a 1999 ERES study *(3)* on diamond-ground PCCPs. With a 10 percent increase in concrete strength, up to ½" of thickness could be removed via diamond grinding and the original design life predicted on the basis of design strength could still be achieved. For a 15 percent increase in strength the thickness reduction could be bumped up to 0.7" without detrimental effects.

Increases in strength occur naturally over the life of a PCCP thanks to continued hydration and pozzolanic reaction. Most PCCP design models use the 28-day strength of concrete. The strength of conventional concrete after one year can be up to 20 % higher than the 28-day strength. Most of Missouri's faulted PCCPs are in the range of thirty to forty years old. Therefore, at this point in time it is not unrealistic to believe that they have acquired a 10 – 15 % strength increase and that they can be reduced in thickness by a reasonable amount without concern over structural soundness, assuming they have not yet succumbed to fatigue.

The 1999 ERES study examined the status of 76 diamond grinding projects, spread throughout the country, that were originally part of a 1989 CPR survey. Based on its survival analysis, the study concluded that a State agency can expect, with a high degree of reliability (>90 %), a minimum life of 8 to 10 years for diamond-ground surfaces.

Diamond grinding, and not undersealing, influences the riding surface of a PCCP. Other diamond grinding studies have focused on this as a single treatment. However, any long term confidence in diamond grinding is tempered by the state of slab support. Diamond grinding must be accompanied by an assurance of adequate support. There are, of course, some pavements with faulted slabs that do not have voids and do not require undersealing, but in the majority of CPR projects this is not the case. This is why undersealing is intertwined with diamond grinding in this report.

The combination of undersealing and diamond grinding as a CPR treatment to correct joint and crack faulting has not been used often in construction. The projects examined in this investigation are the only prime examples of U/D in Missouri, with the exception of two others that were constructed too recently to acquire performance data from. Its use in maintenance has also been minimal. However, the two procedures have been employed separately on a fairly frequent basis.

Undersealing PCCP has been a standard rehabilitation method in Missouri for the past four decades. It usually consists of drilling one or two holes a few feet beyond the joint or crack in the leave slab and injecting a sealant until evidence of the voids being filled are seen. Raising of the slab is kept to a minimum to avoid making the situation worse with uneven support and cracking. The procedure experienced two notable alterations during this period. The first was a switch in 1988 from an asphalt filler to a grout slurry consisting of flyash and cement. The second change was adding deflection testing in 1991 to select appropriate locations for undersealing.

Nearly all undersealing is performed prior to an asphalt concrete (AC) overlay. In these cases, there is little need to grind the PCC surfaces since they are about to be covered, unless there are concerns about compaction or leveling. The window of opportunity for undersealing is limited to when the slab has not yet deteriorated into smaller pieces. Past this point in time the only rehabilitation option for the existing surface is a full depth repair.

Diamond grinding is common on new PCCP construction projects and is performed at the contractor's expense to correct smoothness deficiencies after the concrete has hardened. It was used recently as a contract bid item on two projects, whereby the contractor was paid upfront for the diamond grinding, but at the same time was held to a higher smoothness standard than in a normal project.

Conducting an investigation of the only project specific examples of the U/D combination was necessary to validate it as a PCCP restoration strategy in Missouri.

PROJECT HISTORY

Rt. 171

The Southbound Route 171 pavement section under investigation in Jasper County (formerly Business US 71) was originally constructed in 1950 between Brooklyn Heights and Webb City. The pavement structure consisted of 8" of non-reinforced PCC with 20' joint spacing on 4" of dense graded granular base. Load transfer at the joints was supplied by either dowel bars or some other device. By 1985 the pavement had experienced severe faulting up to ½" at the joints.

When originally constructed this route served as a segment of the main two-lane US 71 thoroughfare. Slightly to the south it entered into the heart of the City of Joplin. Two parallel lanes were added for the northbound direction in 1981 and both lanes in the older pavement became southbound directional. Later as US 71 was relocated to the east, the existing facility became the business route through Joplin. Most truck traffic was diverted to the new US 71 route.

The 1985 rehabilitation contract proposal for Rt. 171 contained diamond grinding, traffic control, and mobilization as the only bid items. The project cost was $154,948 for 3.64 miles of 24' pavement. It appears undersealing was performed under another contract or by maintenance forces shortly before the diamond grinding, but the exact time is unclear due to lack of documentation. In any event, the slabs apparently had adequate support prior to diamond grinding. The joints were ground till the elevation on either side of all the joints were within 1/16" of each other.

I-44

The eleven-mile I-44 pavement section under investigation in western Greene County was built in 1962 between Rt. 266 and the Lawrence County line. I-44 in Missouri is an extremely important piece of the Interstate infrastructure since it runs roughly along the same alignment as old US 66 and serves as the main conduit to the southwestern part of the country. Traffic volumes, especially tractor-trailer combinations, have risen steadily over the past few decades. The pavement structure consisted of 8" of doweled jointed reinforced concrete pavement (JRCP) with 61.5' joint spacing on 4" of dense graded granular base.

By the early 1990s the pavement surface had become rough due to structural irregularities, primarily joint faulting. About that time diamond grinding was recommended to the District Eight Office as a means of buying several years of serviceable pavement life until it could be overlayed or reconstructed. By the time the contract was actually let in 1996, faulting on the original concrete had become very severe, averaging ¾" and even reaching maximum levels of nearly 1 ½" in a few locations. The expected benefits of the U/D proposal had decreased. Despite the limited advantages, it was perceived that no less expensive minor rehabilitation method was available that could do a better job of restoring ride for a reasonable duration.

The 1996 rehabilitation contract proposals for I-44 included both undersealing and diamond grinding, along with substantial full depth pavement repair. A separate bid item for deflection testing with a loaded truck axle or "proof rolling" was included to determine undersealing locations, where full depth repairs would not occur. Four inch slotted pipe drains were installed longitudinally along the entire project length. Lateral outlet drains spaced approximately 375' apart from each other were also included. Total diamond grinding and undersealing related costs were approximately $501,000. Full depth repairs and drainage pipes added another $623,283. Diamond grinding was only performed in the driving lanes. Joints were ground till the elevation on either side of all the joints were within 1/16" of each other.

I-35 LTPP Site

The I-35 LTPP test site in Harrison County is classified as an SPS-6 experimental project, which examined alternate methods of rehabilitating PCCPs. It was constructed in 1992 on the southbound lanes. The rehabilitated pavement was a 9" doweled JRCP with 61.5' joint spacing and was originally built in 1974.

The SPS-6 site has a total of sixteen test sections, but the two of interest to this investigation were the 1000' minimum and maximum restoration sections. The maximum restoration test section, included full depth repairs where needed, U/D, joint and crack sealing, and edge drains. The minimum restoration test section, included all the above, but without any undersealing and without edge drains. The average diamond grinding depth for the I-35 site was ¼". The SPS-6 site also contained a control section, which received no repairs at the time of construction. Construction documents were no longer available, so the actual costs were not known.

The restoration and control test sections required some full depth patch repairs a few years after construction due to faulting and spalling.

Another SPS-6 site with minimum and maximum restoration test sections was constructed in 1998 on Rt. 8 in Washington County. The rehabilitated pavement was a 7" JPCP with 30' joint spacing. Also, an SPS-4 site on I-35 in Daviess County, which was primarily a joint sealant study, received contract repairs in 1999, including U/D. Since neither of these sites was over two years old, there was not enough performance data available to determine any results.

TECHNICAL APPROACH

The I-44 and Rt. 171 investigations were launched separately, shortly after their respective construction dates. The SPS-6 site has been monitored continuously since its construction by the LTPP Regional Contractor.

Rt. 171

Two 500' test sections, spaced a hundred yards or so from each other, were monitored in the driving lane of southbound Rt. 171.

Fault measurements at the joints and general pavement distress surveys were performed annually from 1986 to 1991 and biennially from 1991 to 1999.

In 2000 three subgrade soil samples were extracted from the shoulder adjacent to the test sections for Proctor compaction, Atterberg limit, and in-situ water content analysis.

Recent Automated Road Analyzer (ARAN) data and accumulated equivalent single axle load (ESAL) estimates were also acquired.

I-44

Twelve 1000' test sections, evenly spaced at about one per mile, were monitored in the westbound driving lane of I-44. Eleven 1000' test sections, evenly spaced at about one per mile, were monitored in the eastbound driving lane of I-44.

Each section was tested with the falling weight deflectometer (FWD) every year between 1996 and 1999. Fault measurements at every joint or working crack were taken in late 1999.

In 2000 seven subgrade soil samples were extracted from the shoulder adjacent to the test sections for Proctor compaction, Atterberg limit, and in-situ water content analysis. A dynamic cone penetrometer (DCP) test was performed at several locations through drilled holes in the driving lane.

Recent ARAN data and accumulated ESAL estimates were acquired. Full depth repair quantities, performed within the original project limits since 1996, were also gathered.

I-35 LTPP Site

The restoration and control sections received the usual LTPP testing regimen every year or two, which included International Roughness Index (IRI) measurements and faulting measurements in the wheel paths. WIM data was collected continuously since 1993. Extensive subsurface testing was performed prior to construction. The LTPP database, via the DataPave 2.0 software, provided most of this information.

RESULTS AND DISCUSSION

Rt. 171

Faulting on the Rt. 171 test sections has increased at a slight pace since 1985. Figures 1 and 2 illustrate the progression at each joint. Each joint fault measurement on the graphs is the average of faulting in the inner and outer wheel paths.

Average faulting for the entire Test Section #1 (TS1) is slightly over 1/16", while average faulting for the entire Test Section #2 (TS2) is slightly under 1/16", as shown in Figure 3.

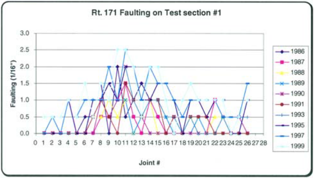

FIGURE 1 Rt. 171 faulting history on Test Section #1

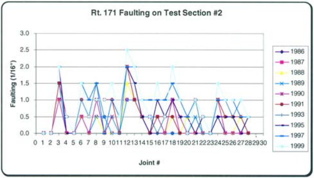

FIGURE 2 Rt. 171 faulting history on Test Section #2

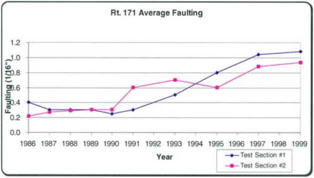

FIGURE 3 Rt. 171 annual average faulting on Test Sections #1 and #2

The 1999 pavement distress survey indicated very little deterioration of the surface in both sections. The exception was a single patch in TS1 and the reason for this was unclear, since the 1997 faulting measurement at this joint was only 1/16". TS1 had no transverse cracks, while TS2 had a total of two. Longitudinal cracking was virtually nonexistent on TS1, but TS2 had roughly 30'. Joint sealant condition at both locations was fairly severe due to missing and oxidized sealant.

The soil sample analysis results are shown in Table 2. The only Proctor test run yielded an unusually high optimum water content at 41 %. This sample's Atterberg test produced a very high plasticity index (PI) of 44. The in-situ water content at this location was well below optimum. Sieve analysis indicated this soil to be inorganic silt with poor workability. The results of the other two samples showed a great disparity with each other and with the first sample. One was a clayey sand with good workability and a Group Index of only 2.4, while the other was a silty clay with fair workability and a Group Index of 22.2. Overall, it is difficult to define the soil properties other than to say they are diverse, and that, despite the single Proctor test, there is a good chance the soil underneath the pavement is on the dry side of optimum.

Rt. 171 Location	LL	PL	PI	% passing #200 sieve	Group Index	ASTM Class.	Proctor Dry density (lb/ft^3)	Proctor Optimum Water %	In-situ water %
TS1 (6th-7th joint)	84	40	44	89	47.8	MH	76	41	29.8
TS1 (21st joint)	33	20	13	44	2.4	SC			12.5
TS2 (17th joint)	46	19	27	82	22.2	CL			20.2

TABLE 2 Rt. 171 soil analysis results

ARAN data collected in 1999 at TS1 and TS2 gave present serviceability ratings (PSR) that were a little above average (close to 30) from a statewide perspective.

The estimate for the total number of rigid ESALs on the SB driving lane is approximately 3 million. By Missouri standards this is a typical level of service for a light duty pavement.

Overall, the performance of the test sections over the fifteen year period have been very good to excellent.

I-44

Faulting was measured in September 1999 on 21 of the 23 test sections on I-44. Tables 3 and 4 highlight the extensive faulting that has resurfaced. Many original joints could not be tested, as evidenced by the low number of joints for most of the test sections, because they had been replaced by full depth patches since 1996. Of the remaining joints, 56 % had faulting ≥ 1/8".

A general visual survey of the rest of the project revealed a high incidence of pumping of water and fines at the joints. This also occurred at roughly a quarter of the new patches placed since the projects were built.

EB I-44			
Test Section #	Location (logmile)	Total # of Joints	# of Joints Faulting ≥ 1/8"
1	0.875 – 1.084	20	11
2	2.067 – 2.165	10	4
3	3.000 – 3.096	9	2
4	4.005 – 4.101	Not tested due to construction nearby	
5	5.433 – 5.614	16	8
6	6.370 – 6.470	14	5
7	7.107 – 7.195	8	7
8	8.007 – 8.097	8	2
9	9.008 – 9.094	10	6
10	10.249 – 10.349	11	7
11	11.008 – 11.098	8	8
Total		114	60

TABLE 3 Faulting on the eastbound I-44 test sections

WB I-44			
Test Section #	Location (logmile)	Total # of Joints	# of Joints Faulting ≥ 1/8"
1	11.785 – 11.697	8	8
2	10.993 – 10.903	9	5
3	9.690 – 9.601	9	7
4	8.993 – 8.905	9	3
5	7.989 – 7.896	10	5
6	7.114 – 7.024	9	7
7	5.992 – 5.902	8	5
8	4.992 – 4.905	Not tested due to construction nearby	
9	3.991 – 3.902	8	6
10	2.585 – 2.405	19	7
11	2.073 – 1.984	9	6
12	0.703 – 0.520	16	9
Total		114	68

TABLE 4 Faulting on the eastbound I-44 test sections

The amount of full depth patching placed within the limits of the two projects since they were completed in the summer of 1996 has been significant. Their quantities and associated costs are shown in Table 5.

Year of Repair	Maintenance Force Repairs		Construction Contract Repairs	
	Quantity (YD^2)	Cost ($)	Quantity (YD^2)	Cost ($)
1996*	500**	35,000	-	-
1997	2059	144,130	-	-
1998	3776	264,320	-	-
1999	2309	161,630	-	-
2000	-	-	3850	270,000
Totals	8644	605,080	3850	270,000
TOTAL QUANTITY = 12,494 (YD^2)		***TOTAL COST = $875,080***		
UNIT COST ~ $4640/ lane mile/year				

* Approximately four months
** Estimate

TABLE 5 Full Depth Repairs on I-44 between Rt. 266 and Lawrence County line

Data from FWD testing performed in 1999 was analyzed using the AASHTO design-based DARWin software program. The test sections indicate that the PCCP pavement, where it is whole, has attained higher flexural strength (~ 780 psi) and modulus of elasticity (~ 6.5 mil psi) during its 38 years of service. However, the average static modulus of subgrade reaction (k-value), was only around 130 psi/in, indicative of poor support underneath the pavement. The results of this analysis were compromised somewhat by the lack of actual slab thickness values.

Load transfers at the test section joints were also measured with the FWD. Unfortunately, only half of the pavement test sections on the westbound side and none on the eastbound could be accurately tested, because of high pavement temperatures. The sections that could be tested reliably provided mostly poor load transfers (< 70 %).

DCP testing was performed at several locations in the eastbound driving lane. The penetration index (PI) readings were converted to California Bearing Ratio (CBR) values using a widely adopted Corp of Engineers (COE) formula and to Illinois Bearing Values (IBV), a modified CBR measure that the Illinois Department of Transportation (IDOT) has developed to correlate more closely to their soils. Normally, a CBR value less than or equal to 6 is indicative of a soil requiring stabilization in order to provide adequate support to a pavement structure.

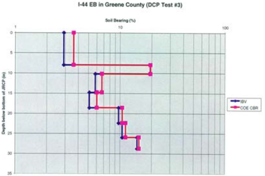

FIGURE 4 DCP results on EB I-44 under old PCCP

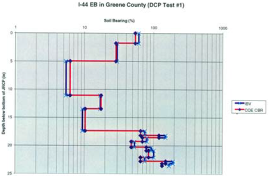

FIGURE 5 DCP results on EB I-44 under repair patch

Figure 4 shows rapid DCP penetration under an old section of PCCP after getting past the base material. Figure #5 shows similar results under a recent repair patch, but the immediate high penetration indicates a loss of base material. Both figures clearly illustrate the poor condition of the top 6"-7" of the subgrade.

Table 6 shows the I-44 soil analysis. The two Proctor compaction tests run on samples from the eastern end of J8I0630 provided similar results with an average of 14.5 % optimum water content. The in-situ water content at this site and at four others within a few miles from it were an average of 4-5 % over optimum. The single Proctor test run at the western end of J8I0631 gave a significantly higher optimum water content. The in-situ water content at this site was 6.1 % over optimum, but the in-situ water content a half mile away was 2.2 % below optimum. The sieve and hydrometer analysis showed more pronounced inconsistency from site to site, which seemed indicative of different borrow sources for the original construction.

I-44 mile marker Location in shoulder	LL	PL	PI	% passing #200 sieve	Group Index	ASTM Class.	Proctor Dry density (lb/ft^3)	Proctor Optimum Water %	In-situ water %
71+2/10 (WB)	29	18	11	69	5.5	CL	110	15	18.5
70+6/10 (WB)	38	18	20	81	15.3	CL			17.5
69+6/10 (WB)	30	19	11	80	7.4	CL	109	14	21
69+1/10 (WB)	37	18	19	80	14.2	CL			20.2
68+5/10 (WB)	28	19	9	70	4.4	CL			16.2
60+9/10 (EB)	48	19	29	65	16.7	CL			22.8
60+4/10 (EB)	69	25	44	56	21.2	CH	96	25	31.1

TABLE 6 I-44 soil analysis results

ARAN data was collected within the projects' limits. The trace results for ride are shown in the Appendix for the years 1995-8. The traces clearly show the rough condition at the joints in September 1995, the smooth condition about a month after rehabilitation in October 1996, and the subsequent return to rough conditions, although probably not to the same magnitude, a year later in December 1997.

Based on WIM scale data there were approximately ten million rigid ESALs on each driving lane during the past three and a half years. By Missouri standards this is a typical level of service for a heavy duty pavement.

Overall, the performance over the past three and a half years of the test sections, and of the projects as a whole, has been poor. Resurfacing projects will be let for the two halves of pavement in fiscal year 2001.

I-35 LTPP Site

The IRI measurements taken over the past eight years probably provide the best indicator for the performance of the SPS-6 test sections. Table 7 gives a general idea of how IRI relates to ride *(4)*. Figure 6 shows how the ride on both the minimum and maximum restoration sections at first decreased substantially to a fairly smooth level, but within seven years deteriorated to a level nearly equal with the control section. The initial IRI measurements were taken prior to restoration. Some full depth patch repairs were performed in 1995, but did not appear to interrupt the progression toward higher IRIs.

Approximate IRI (in/mile)	Ride classification
0-95	Smooth
95-133	Moderately rough
>133	Rough

TABLE 7 IRI correlation with ride

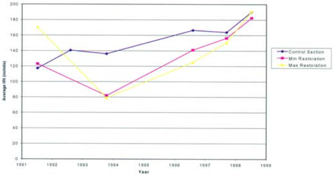

FIGURE 6 I-35 SPS-6 test section IRI performance history

Prior to construction, faulting did not exceed 5/16" at any location on the minimum restoration section and did not exceed 7/16" at any location on the maximum restoration section. The results of the subsequent surveys are shown in Figure 7. The August 1992 survey, conducted soon after construction, indicates virtually no faulting at the joints of the two restoration sections. The full depth patch repairs performed in 1995 occurred mostly at transverse cracks and did not result in any noticeable improvement in joint faulting. The control section underwent multiple maintenance repair operations, which explains the noticeable improvement after 1995. Average wheel path faulting measured during the last survey shows the three sections approaching the same value.

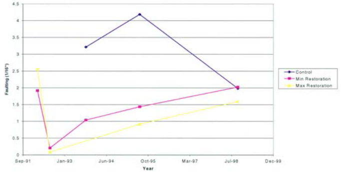

FIGURE 7 I-35 SPS-6 test section faulting performance history

Sieve analysis determined the subgrade soil to be a sandy clay. Proctor tests run on subgrade soil samples yielded an average optimum water content of 15 % for both restoration sections. The in-situ water content for the minimum restoration section was 18 %, while it was slightly over 20 % for the maximum restoration section. The original pavement distress survey sheets for these two sections showed some degree of pumping occurring at virtually every joint and working crack.

Based on WIM data accumulated since 1993, the I-35 test sections have carried approximately six million rigid ESALs. By Missouri standards this is a typical level of service for a medium duty pavement, however, since it is an Interstate route the pavement should be designed to heavy duty standards.

Undersealing and edge drains did not appear to make any appreciable difference in performance between the two restoration sections.

Overall, the restoration test sections performed adequately over a short period of time. Compared to the adjacent control or "do nothing" section, they clearly provided a smoother riding surface. However, their cost effectiveness was clouded somewhat by the fact that they required maintenance repairs within a couple of years after construction. At present the two restoration sections and control have regressed to such unacceptable levels that emergency repairs, probably full reconstruction, are being planned for FY 2001.

Discussion of Results

The different investigations of U/D projects produced uneven results. An investigation with a unified work plan for the selection of U/D projects would have eliminated some of the disparity and provided a more coherent analysis of the data. However, the manner in which these projects were independently evaluated precluded this from happening.

The Route 171 project performed well, probably beyond anyone's original expectations. There is currently no justification to consider rehabilitating the pavement in the near future.

The I-44 projects appeared to have only momentarily halted the pavements' rate of deterioration. The prevalent faulting distress reappeared within a year after they were completed. Since then, District Eight maintenance personnel have been constantly making full depth patch repairs to keep the riding surface tolerable.

The I-35 minimum and maximum restoration test sections yielded better results than the I-44 ones. They too returned to a rehabilitation-triggering level of roughness, but at a slower speed of deterioration. Keeping in mind that a few emergency repairs at transverse crack locations were required in 1995, they provided an acceptable level of service for approximately four to five years.

The differences in project circumstances need to be highlighted here to help explain some of the possible causes of differences in project performances.

1) Subsurface conditions - The results of the soil samples analyses and the DCP testing are not completely conclusive, but do provide some insight. There is little doubt, based on DCP testing under the I-44 driving lane and on the amount of pumping observed both under old pavement and new patches, that prevalent near the surface lies a layer of saturated soil with little bearing capacity. Proctor compaction and in-situ water content testing on the I-44 samples seem to indicate a soil that is well above the optimum water content in its natural state. FWD testing on a portion of the westbound test sections revealed poor load transfers at the majority of the joints. The I-35 test sections had also exhibited a lot of pumping prior to restoration. Subgrade in-situ water contents at these sections were well above optimum. Rt. 171 soil tests were less clear, but hinted that the in-situ state was on the dry side of optimum.

2) Faulting severity – At the time of Project 7-P-71-329 faulting on Rt. 171 had achieved levels of up to ½". These were severe, but not nearly as bad as the faulting on I-44, which prior to its diamond grinding project had ¾" average and 1 ½" maximum faulting. The degree of faulting and the high number of full depth patch repairs suggested a loss of support not easily restored by undersealing. In fact, at the time the U/D work was performed, the expected return of benefits had diminished.

The work on I-44 simply had to be done, because there was no other effective rehabilitation option available whose cost would fall within the allotted budget for that fiscal year. With respect to the others, the I-35 test sections were the least severely faulted, averaging a little less than 3/16".

3) Traffic loadings – Rt. 171, once part of the main US 71 thoroughfare, had been relegated to secondary status for commercial vehicles. Accumulative truck loadings on this route over the past fifteen years amounted to about three million ESALs. By comparison the I-44 driving lanes have already absorbed ten million ESALs in three and a half years and the I-35 test sections have endured six million in seven years.

A direct cost analysis between the project sites is difficult to break down because of the different preexisting distress conditions, different project magnitudes, different levels of rehabilitation effort, and lapse of time. However, cost effectiveness for individual sites can be discussed.

On Rt. 171, an asphalt concrete (AC) overlay, which was and still is the standard treatment for correcting old rough PCCPs, would have easily doubled the cost of diamond grinding. Both strategies would have required the same amount of undersealing and full depth repairs. Therefore, considering that a period of time has elapsed equivalent to the average life span of an AC overlay, it is clear that a significantly less expensive solution was chosen with the same benefits.

Unlike Rt. 171 , the projects on I-44 included drainage pipe installation. On paper this would appear to have skewed the performance in favor of the undersealing and diamond grinding, since it should have helped eliminate future pumping and subsequent faulting. However, very poor subsurface conditions with high in-situ water content and highly plastic fines seemed to have neutralized any benefits from the drainage pipe installation. This probably made the projects even less cost effective than had they relied solely on U/D. Also, the rapid return of faulting, although not to the same level of severity, limited the success of the U/D procedure itself.

Both restoration test sections on the I-35 SPS site provided at least four years of moderately improved ride over the adjacent control section. From a performance standpoint they were successful. However, the other test sections within the SPS-6 site, primarily different types of AC overlays, are still functioning at acceptable levels and will have longer performance lives. Therefore it is difficult gauge their cost effectiveness among alternate rehab techniques. It should be mentioned, though, that the original condition of the test sections were not as uniform as would have been hoped for and so the disparity in costs of initial repairs will partially influence any future cost analyses. With respect to each other, the maximum restoration section, which was retrofit with edge drains, was not noticeably superior to the minimum restoration section. Therefore, the minimum restoration section was more cost effective.

In summary, two of the projects examined in this study may have represented extreme ends of the U/D spectrum. Neither the 14+ -year longevity of the Rt. 171 project nor the very limited duration of the I-44 projects can serve as the basis for determining an average U/D design life. Not nearly enough data is available from Missouri U/D projects to provide statistically sound mean life spans under different loading and environmental conditions. However, we can at least say that U/D buys time till major rehabilitation can occur. This view is reinforced by evidence from many diamond grinding projects completed outside of Missouri. A range of five to ten years, depending on truck volume and existing pavement structure, appears to be a reasonable range until further refined.

CONCLUSIONS

General:

1) Undersealing/diamond grinding can be an effective CPR technique under the right conditions.

Specific:

2) Diamond grinding an older PCCP at the joints, that is adequately supported and structurally sound, should not compromise slab performance.

3) Evidence of widespread pumping and highly plastic fine-grained subgrade soils with high in-situ water contents may likely eliminate a PCCP from being a candidate for U/D.

4) Retrofitting edge drains provide little, if any, additional benefit to pavements with fine-grained subgrade soils.

5) U/D should not be expected to provide more than five years of reasonable service to a PCCP with high cumulative ESALs.

6) U/D may provide ten years or more of service to a PCCP with low cumulative ESALs.

RECOMMENDATIONS

1) PCC pavements that meet the following criteria, pending an appropriate evaluation, may be eligible for U/D restoration without additional rehabilitation:

   - have relatively intact slabs without excessive transverse cracking
   - have good load transfer
   - have average faulting to a depth that will not compromise the structural integrity of the pavement slab when removed (typically ≤ ½")
   - do not have highly plastic subgrade soils, with in-situ water contents well above optimum, that are prone to widespread pumping

2) Design life assumptions for PCC pavements that receive U/D restoration should fall within the following ranges:

   - no more than five years for pavements defined as heavy duty by ESAL loadings
   - five to ten years for pavements defined as light or medium duty by ESAL loadings

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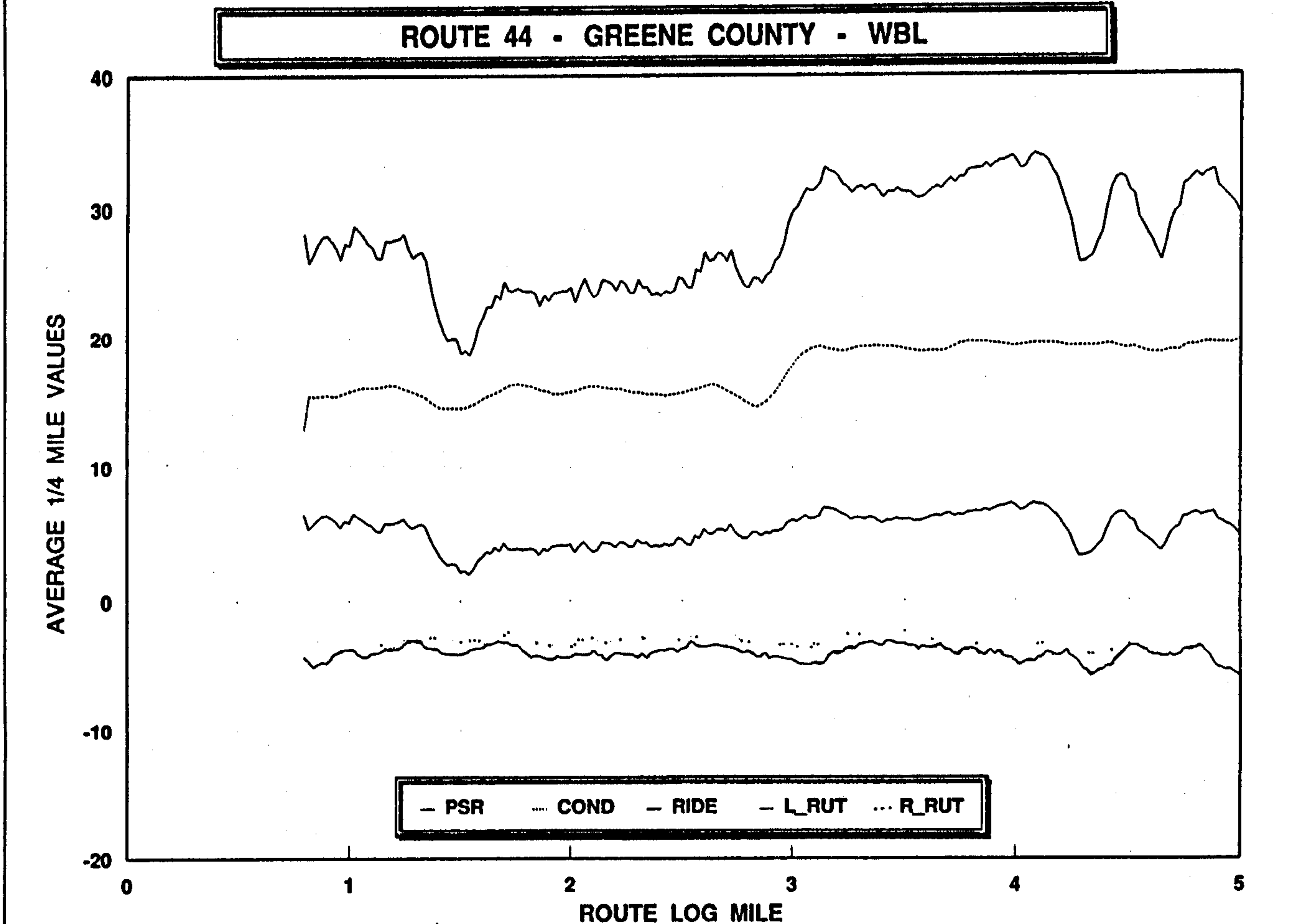
APPENDIX



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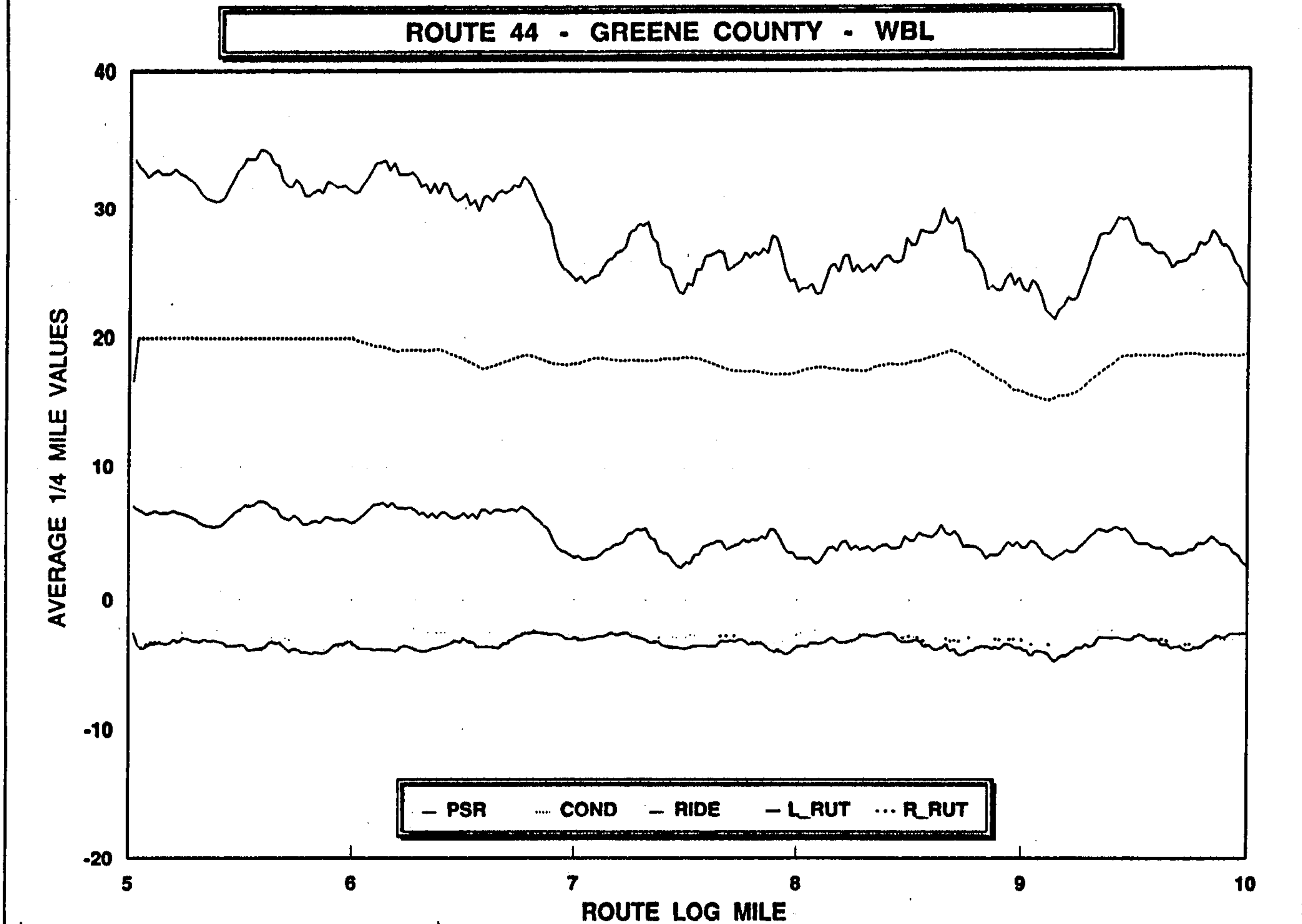

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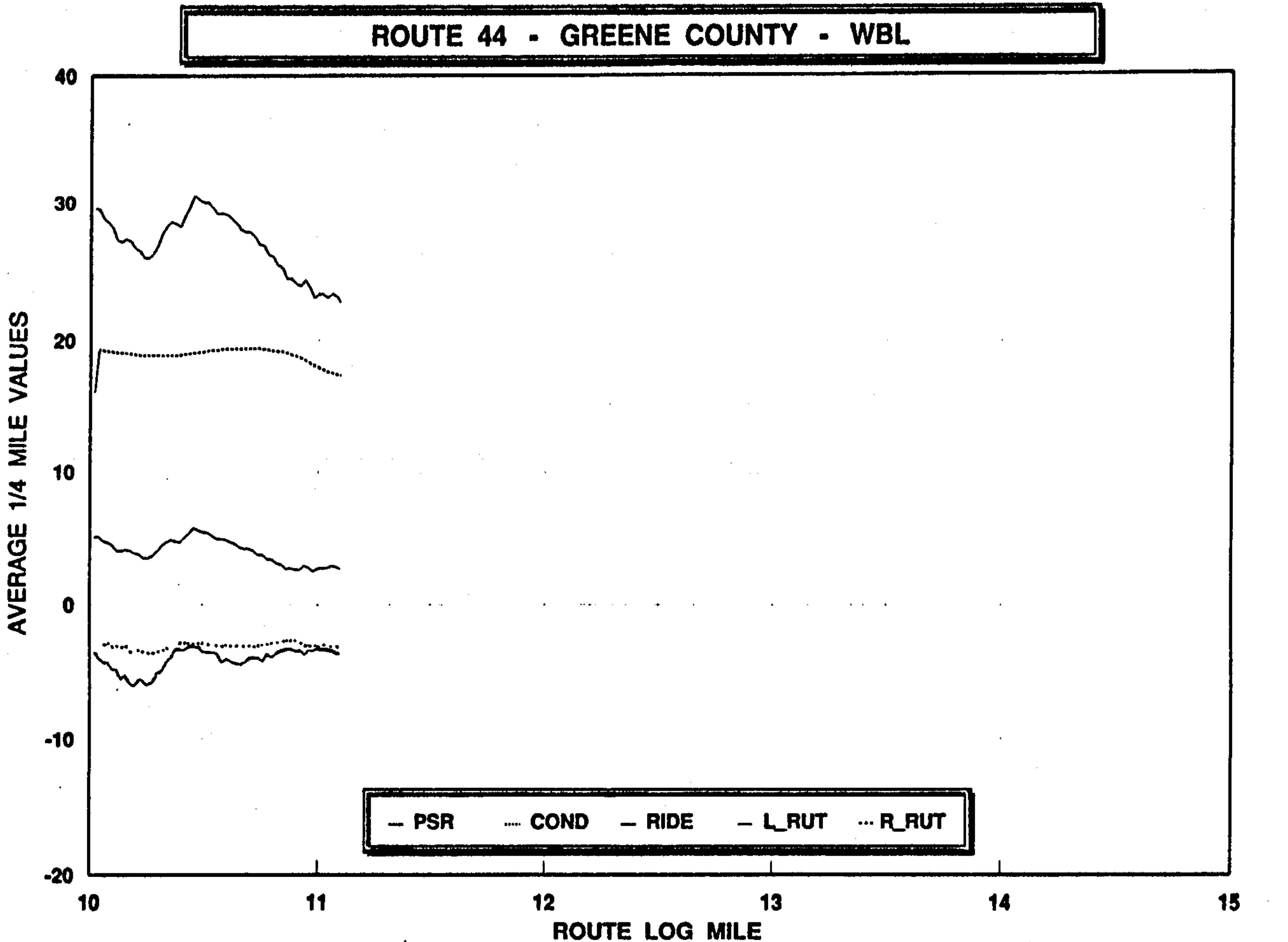

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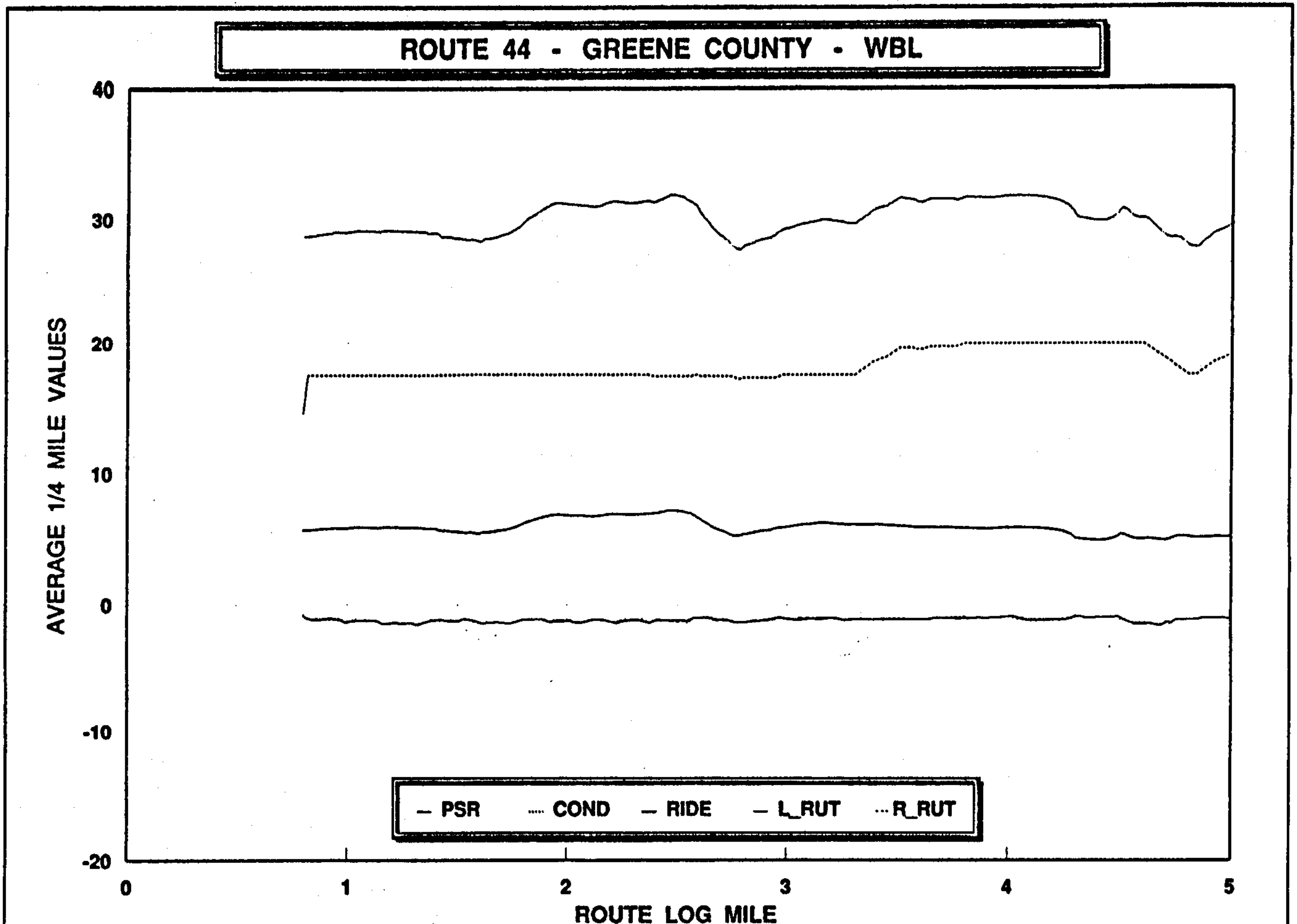

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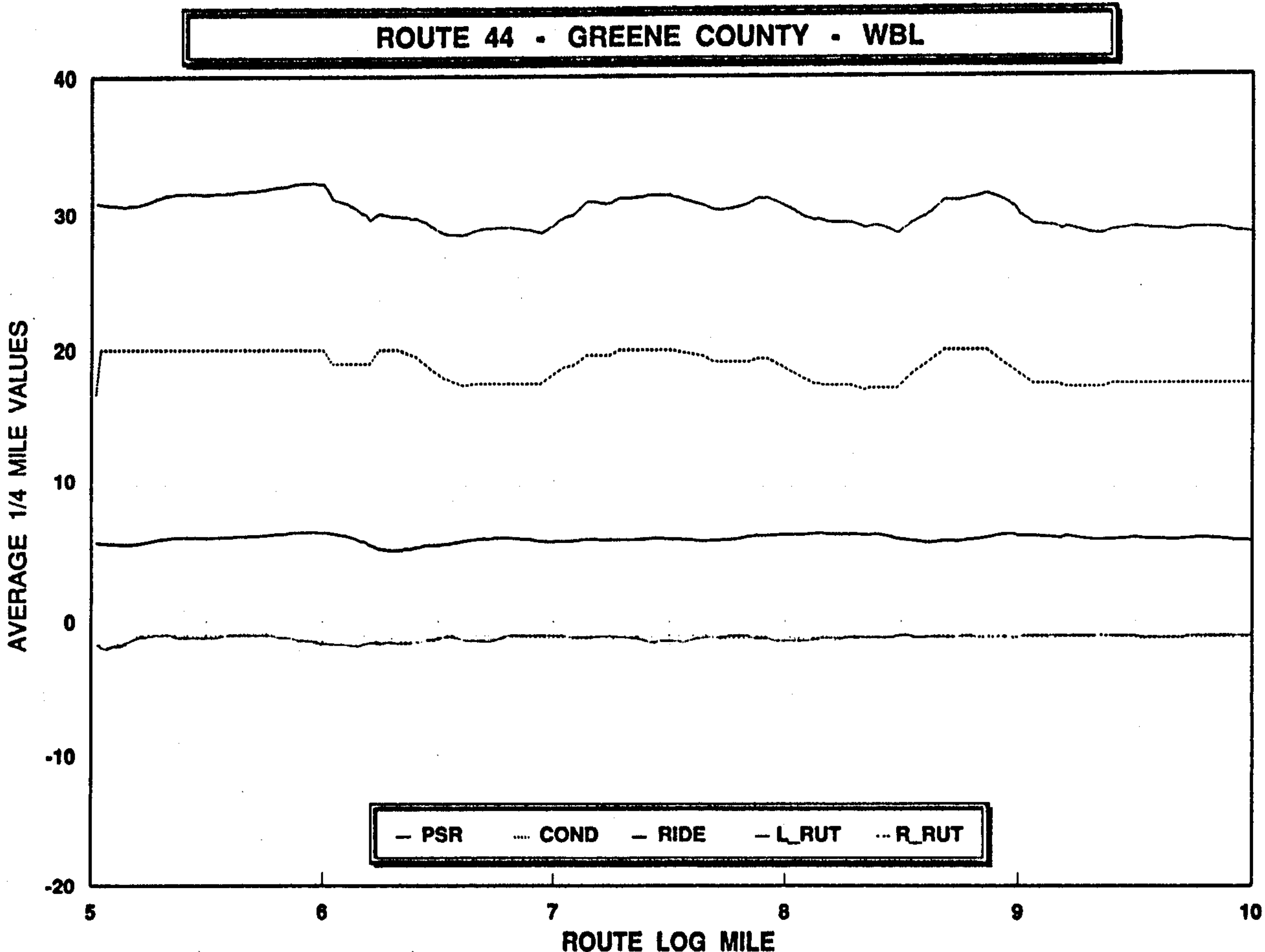

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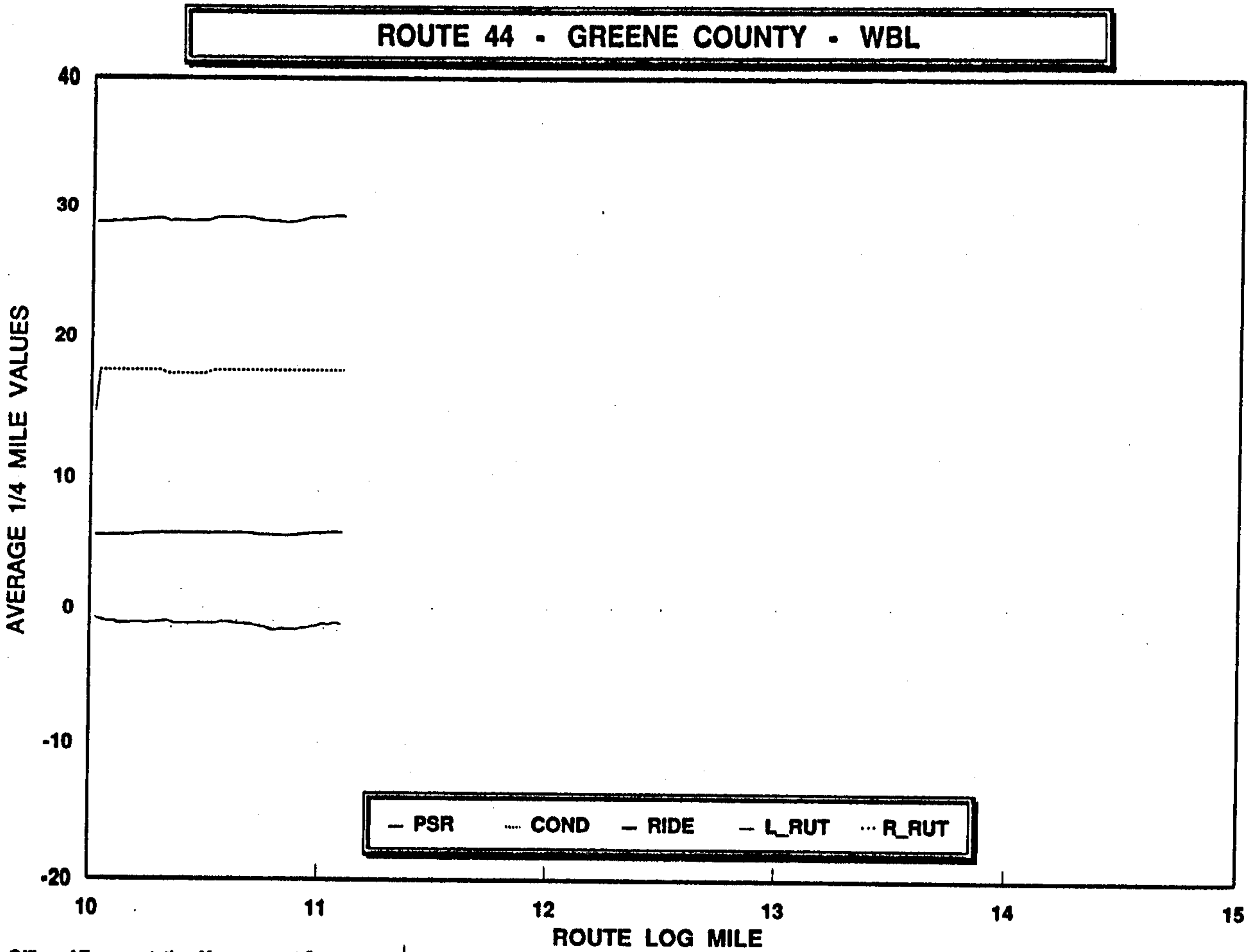

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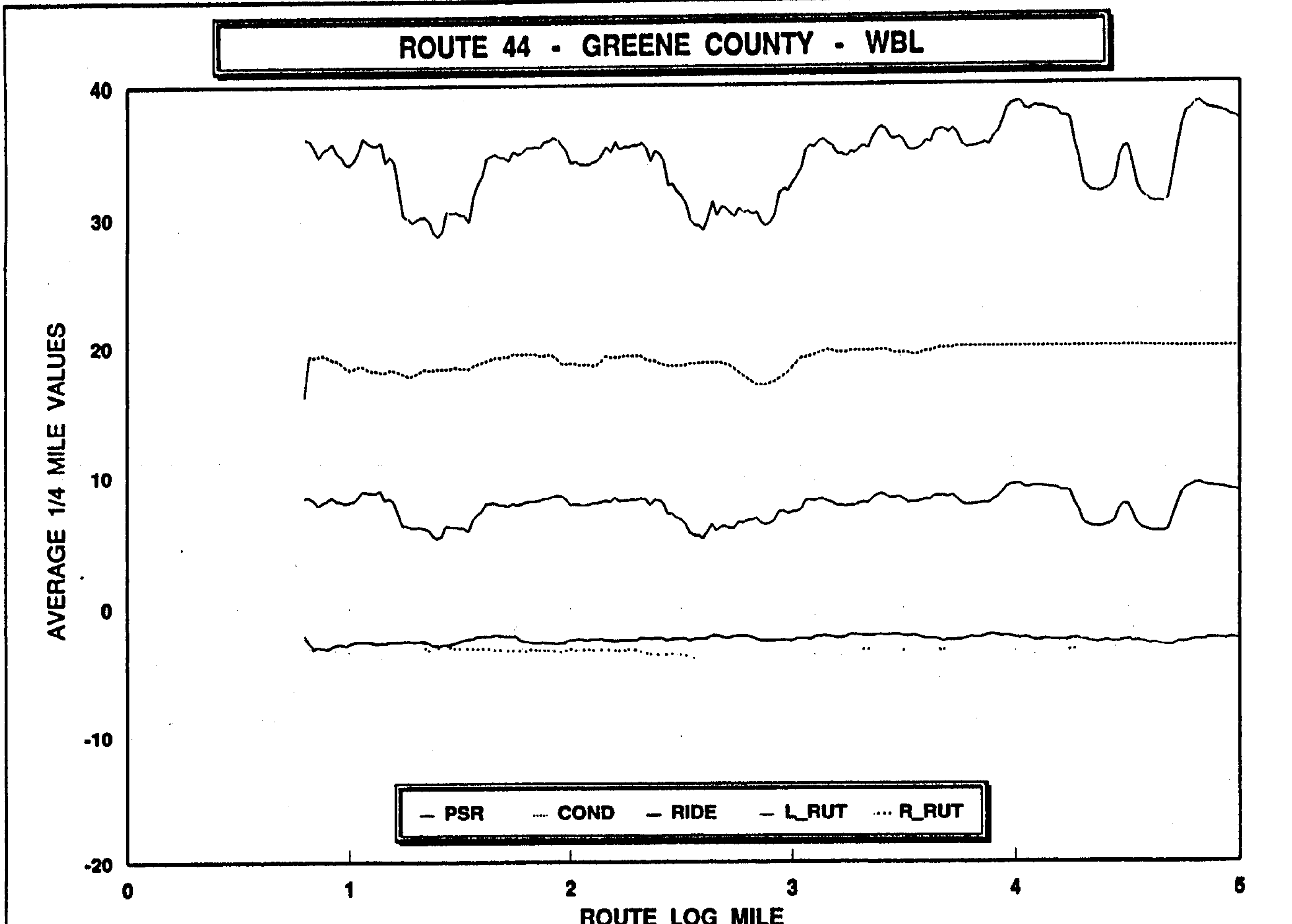

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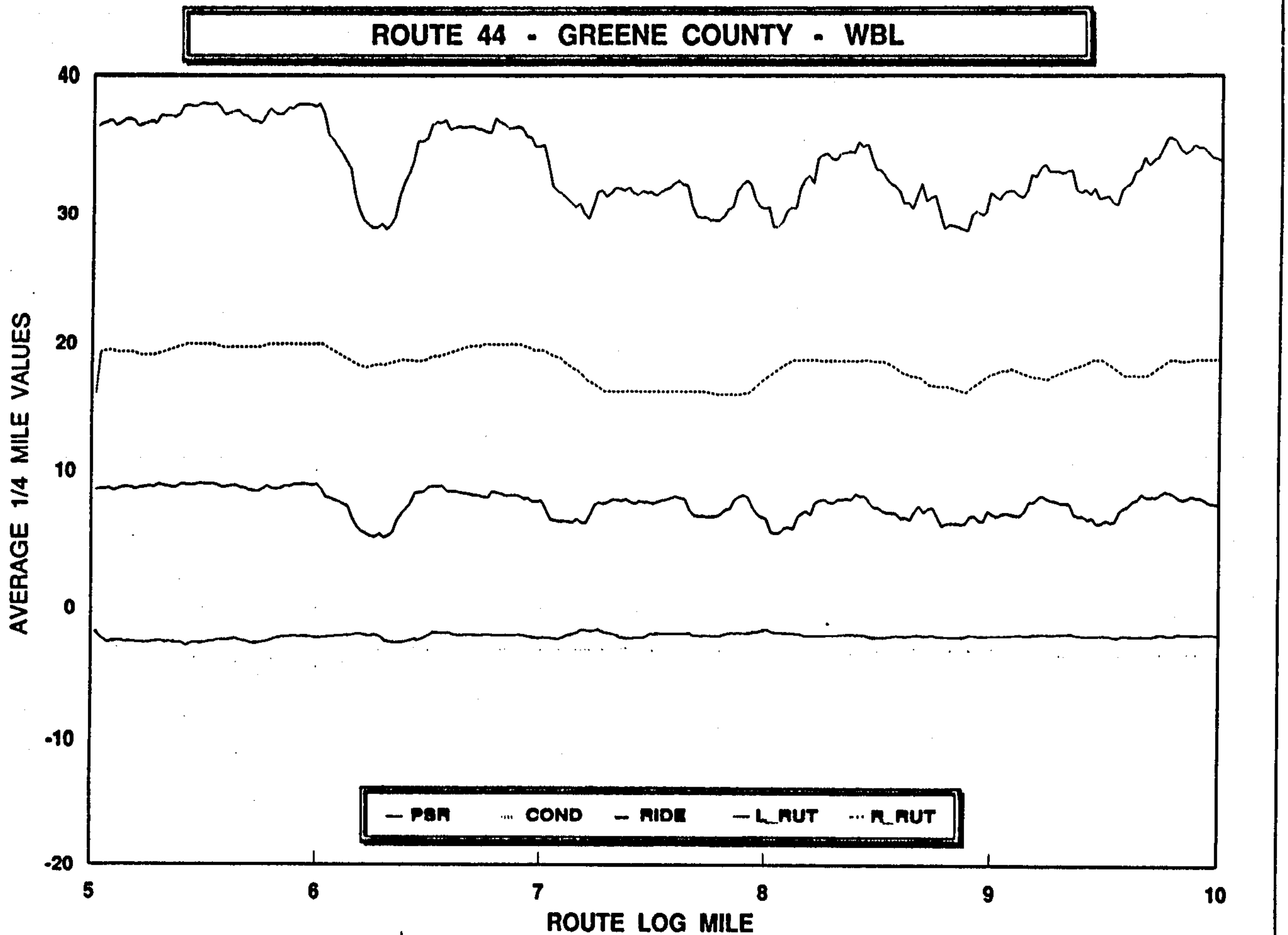

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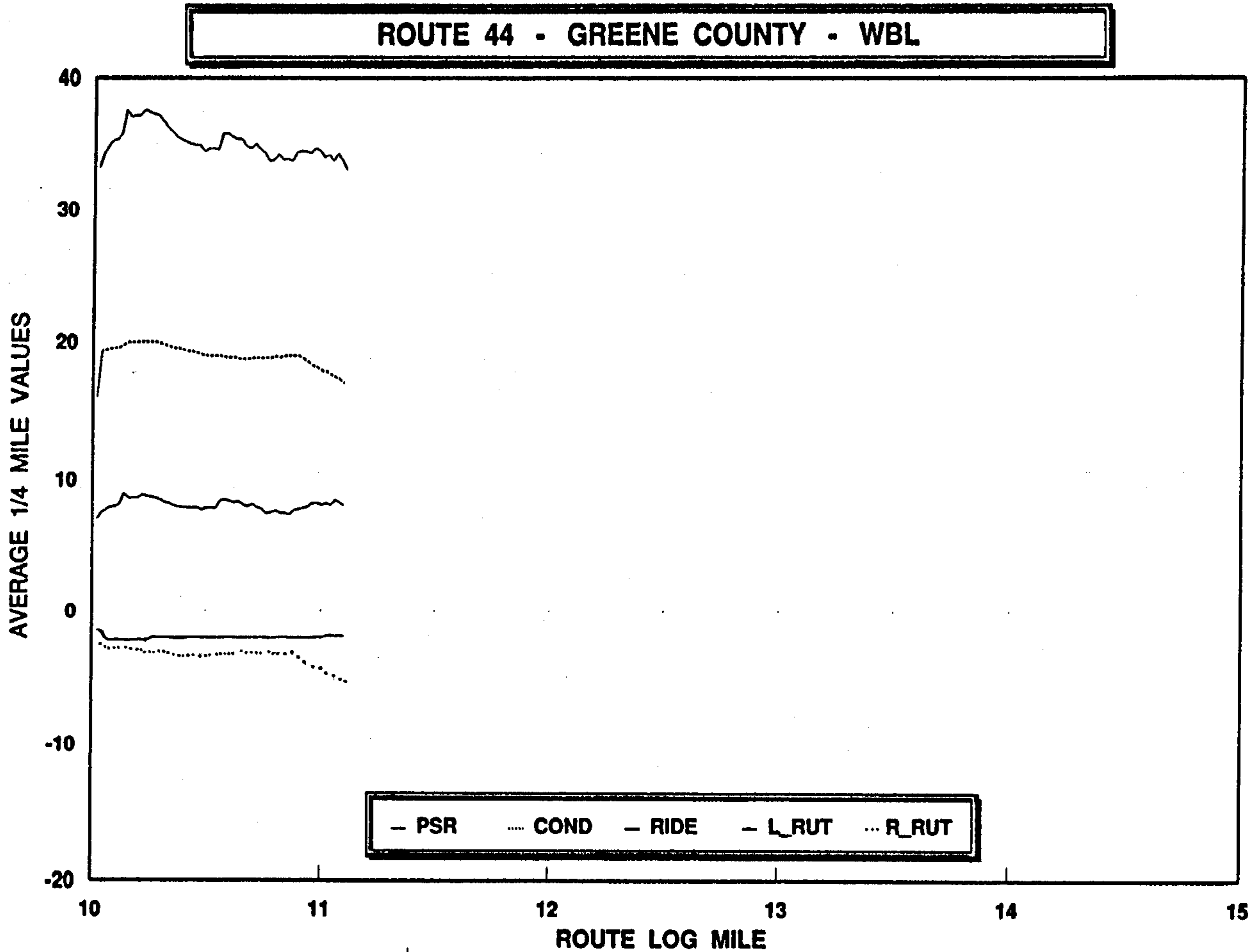

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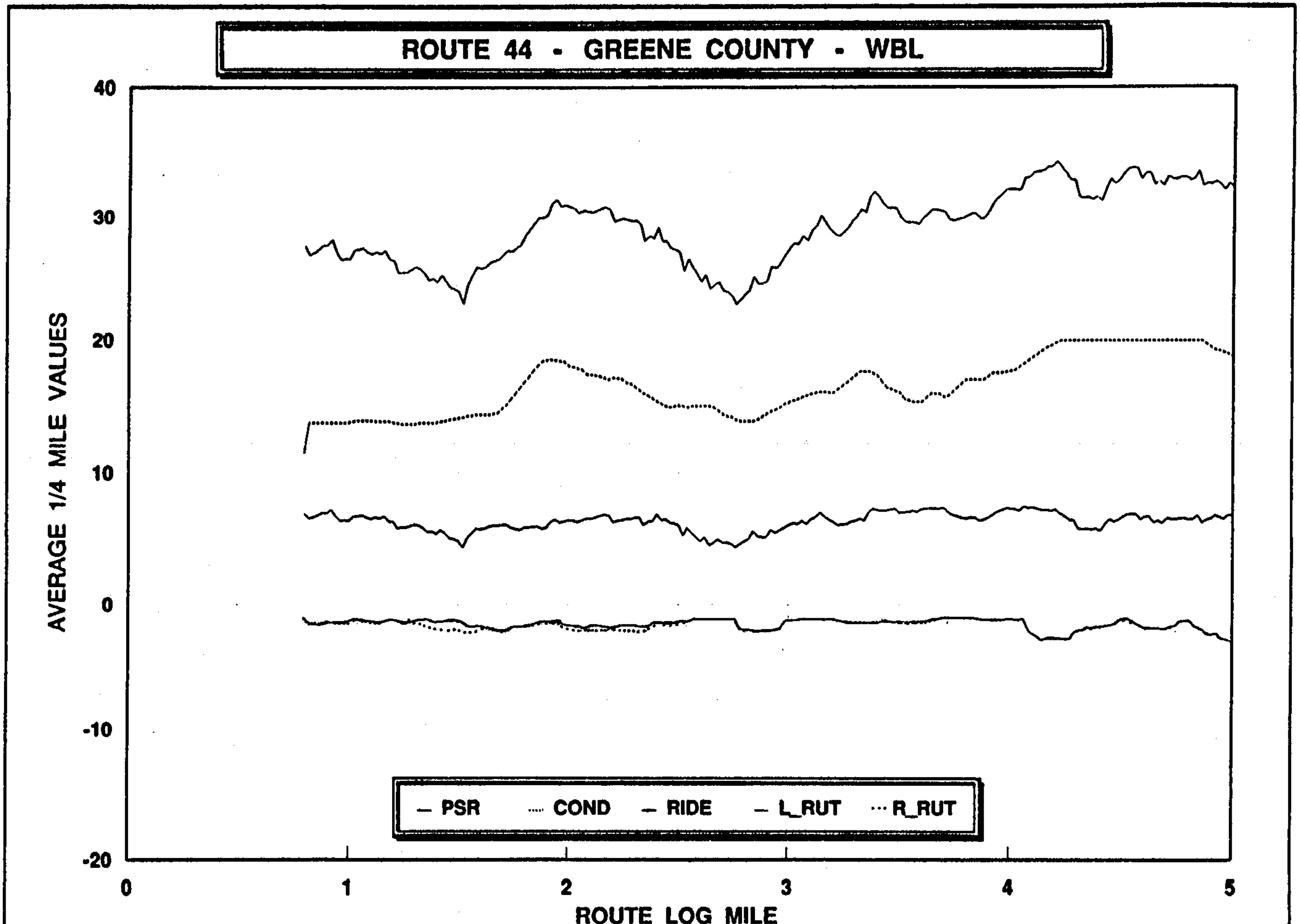

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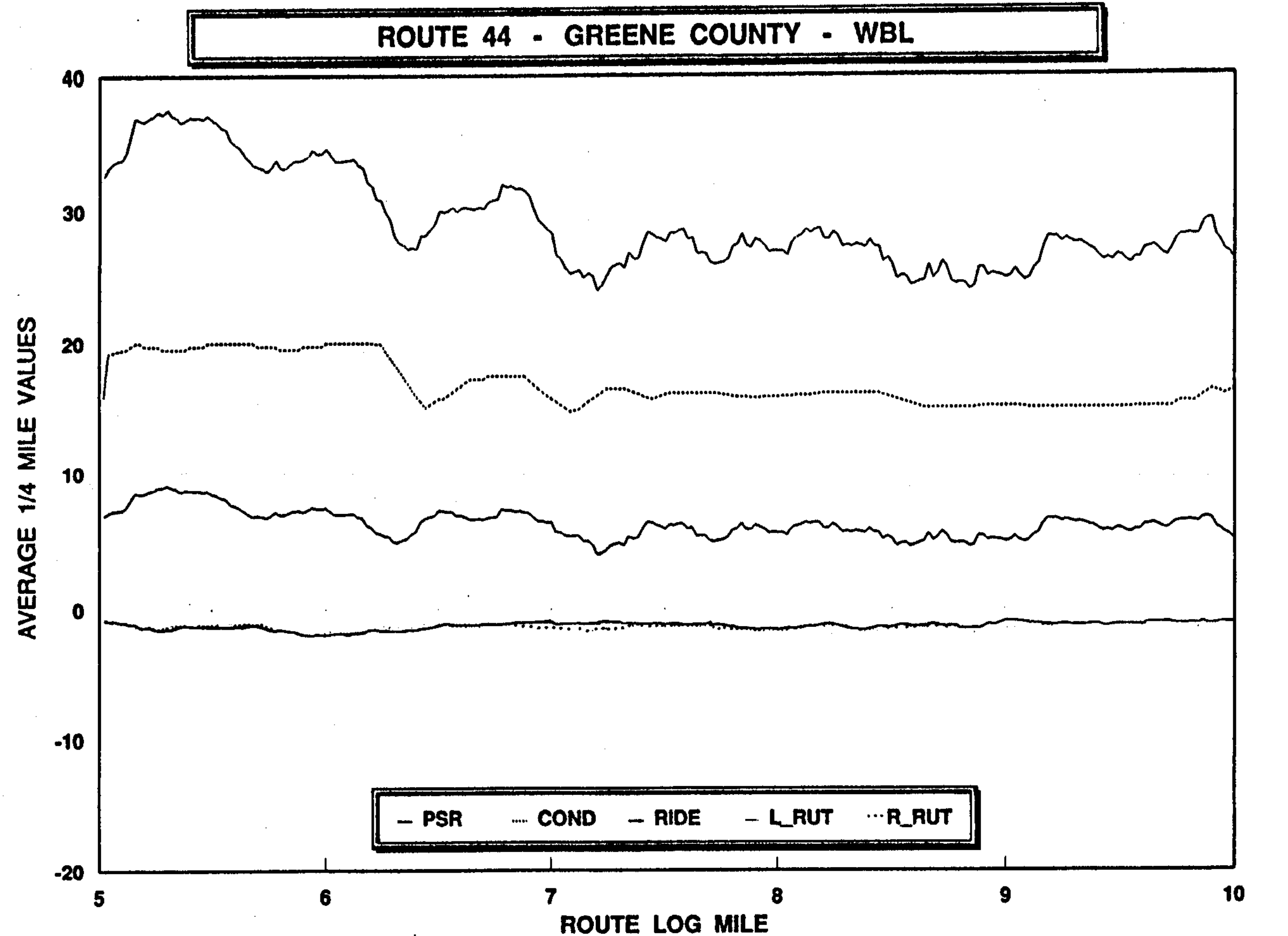

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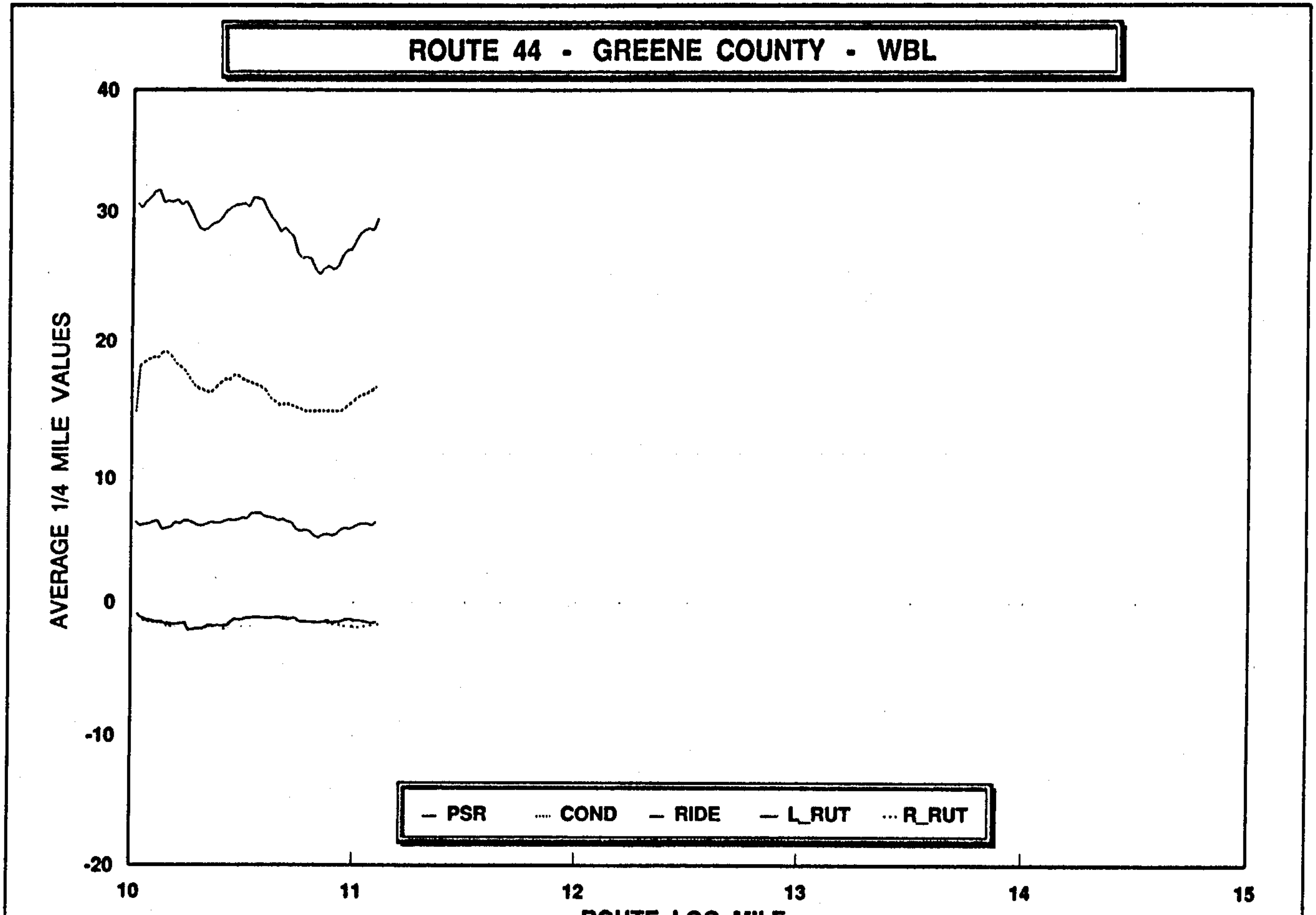

ROUTE 44 - GREENE COUNTY - WBL
AVERAGE 1/4 MILE VALUES
40
30
20
10
0
-10
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ROUTE LOG MILE
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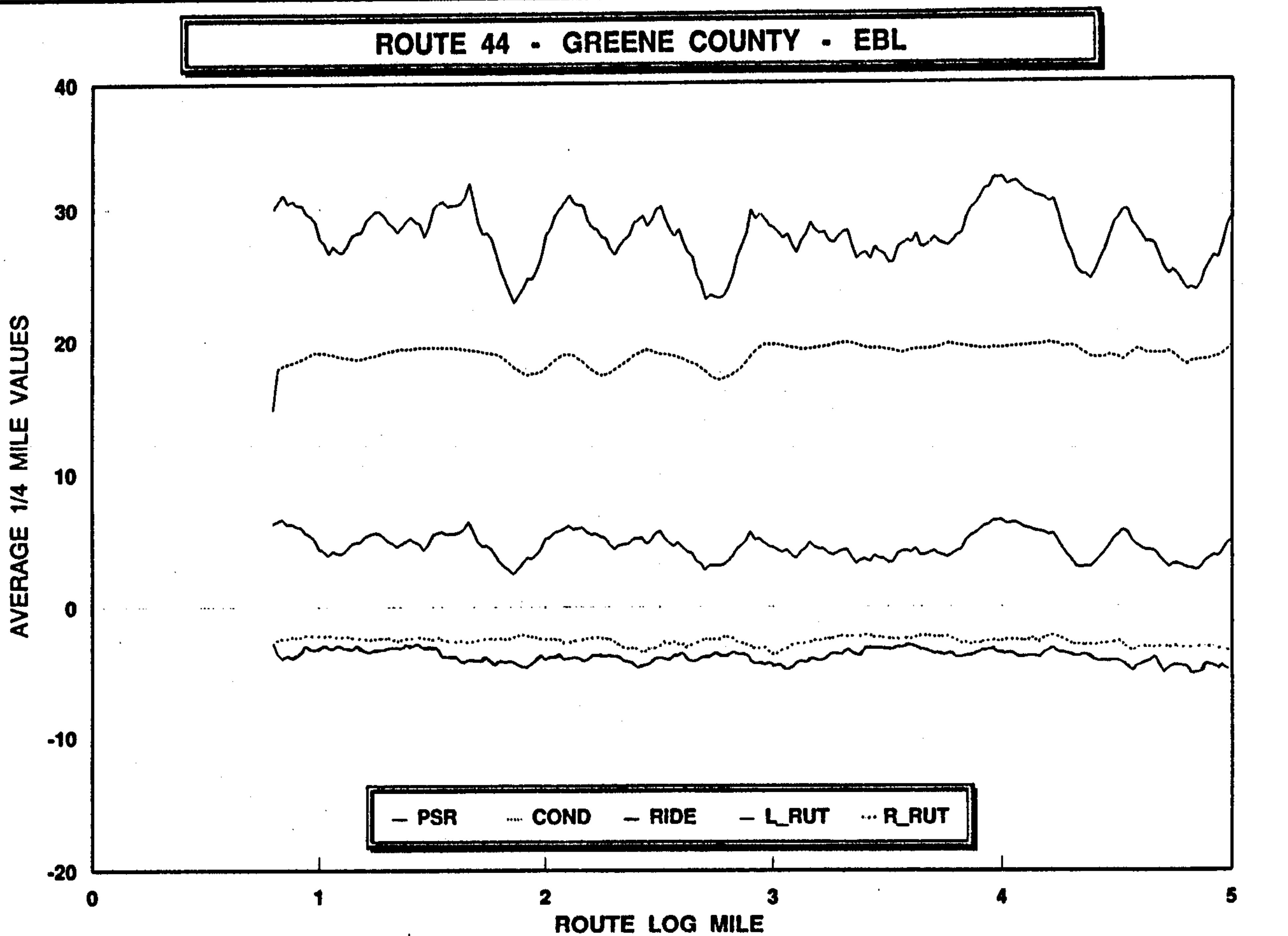
— RIDE
— L_RUT
··· R_RUT



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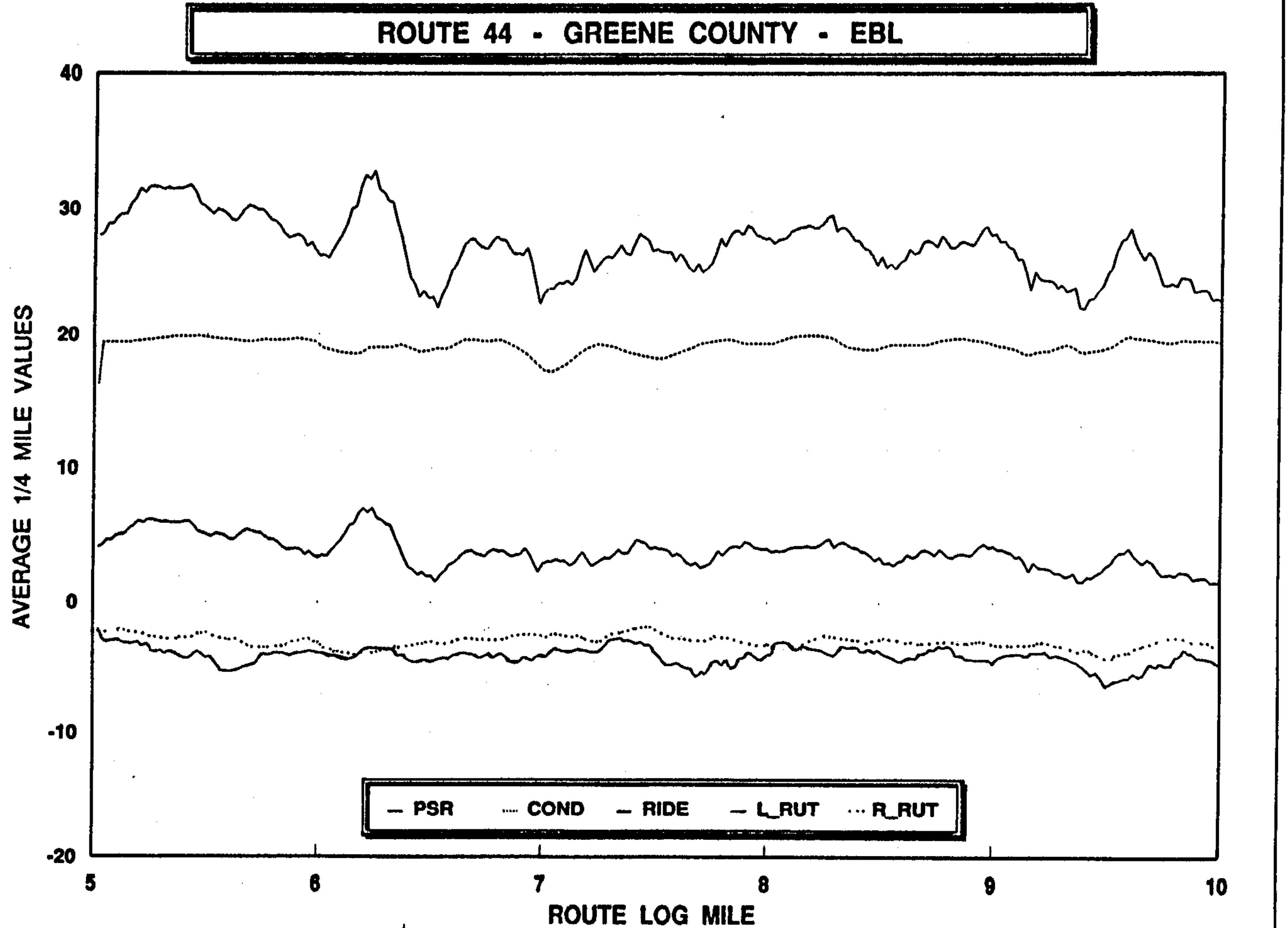

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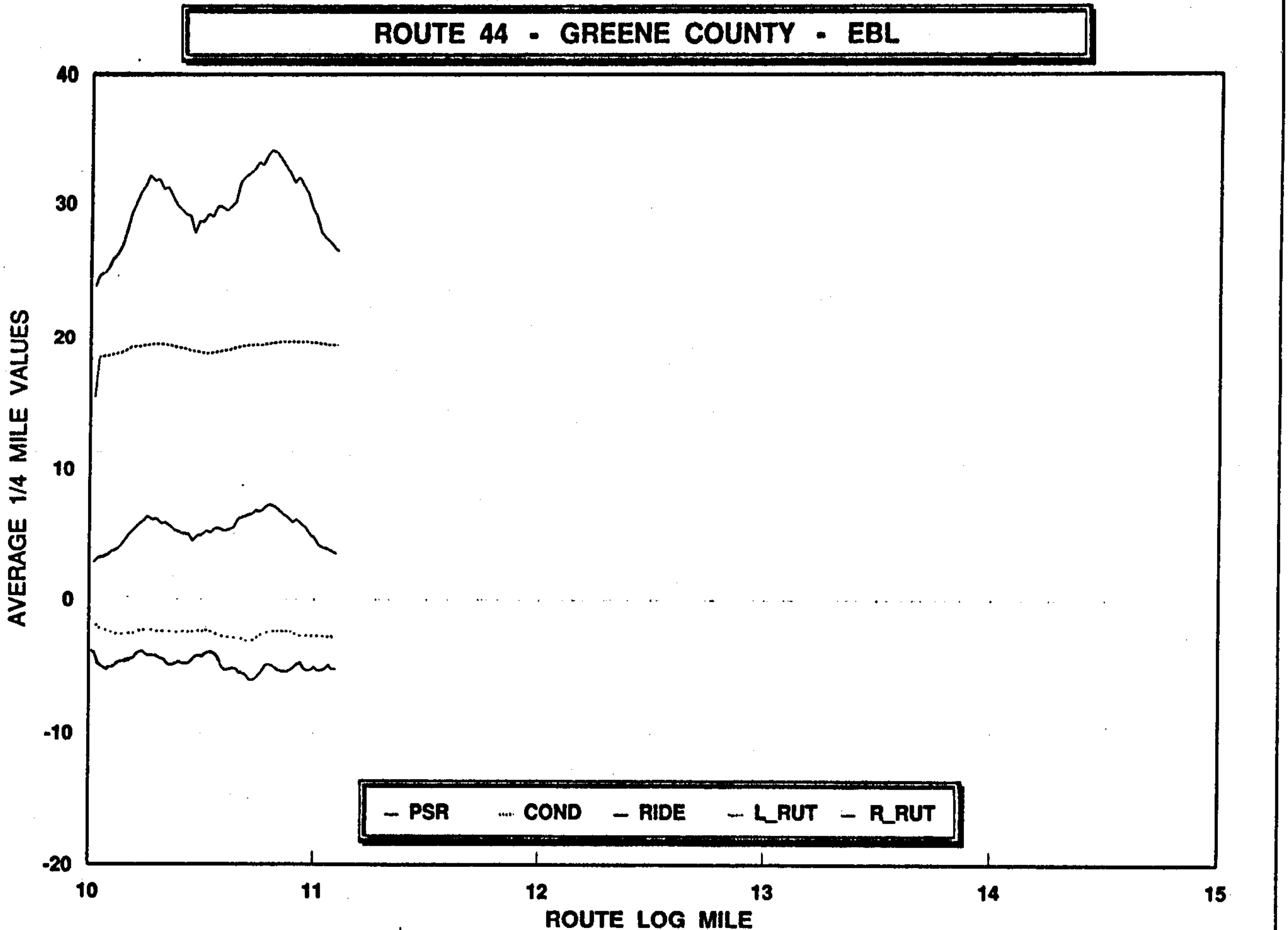

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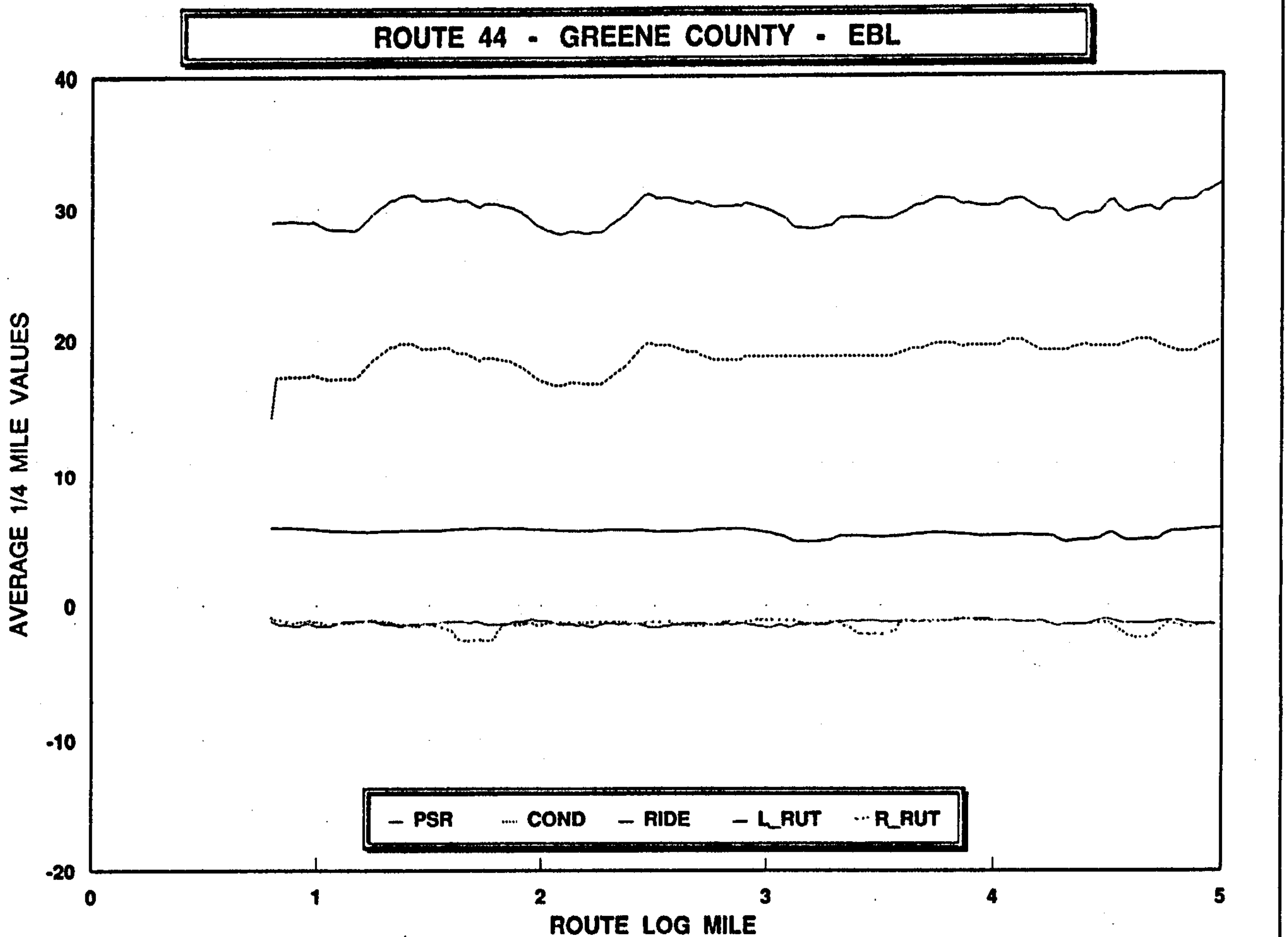

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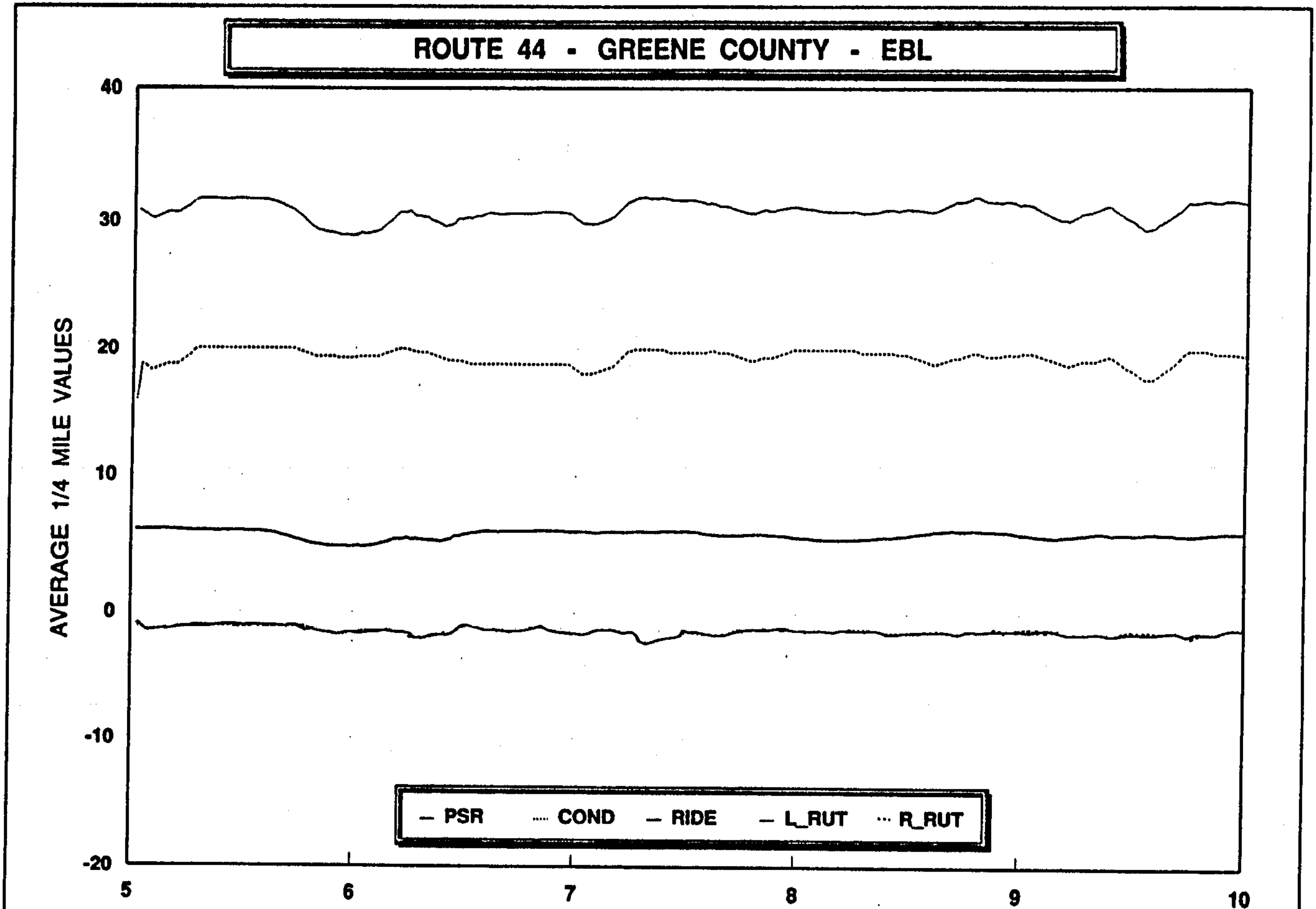

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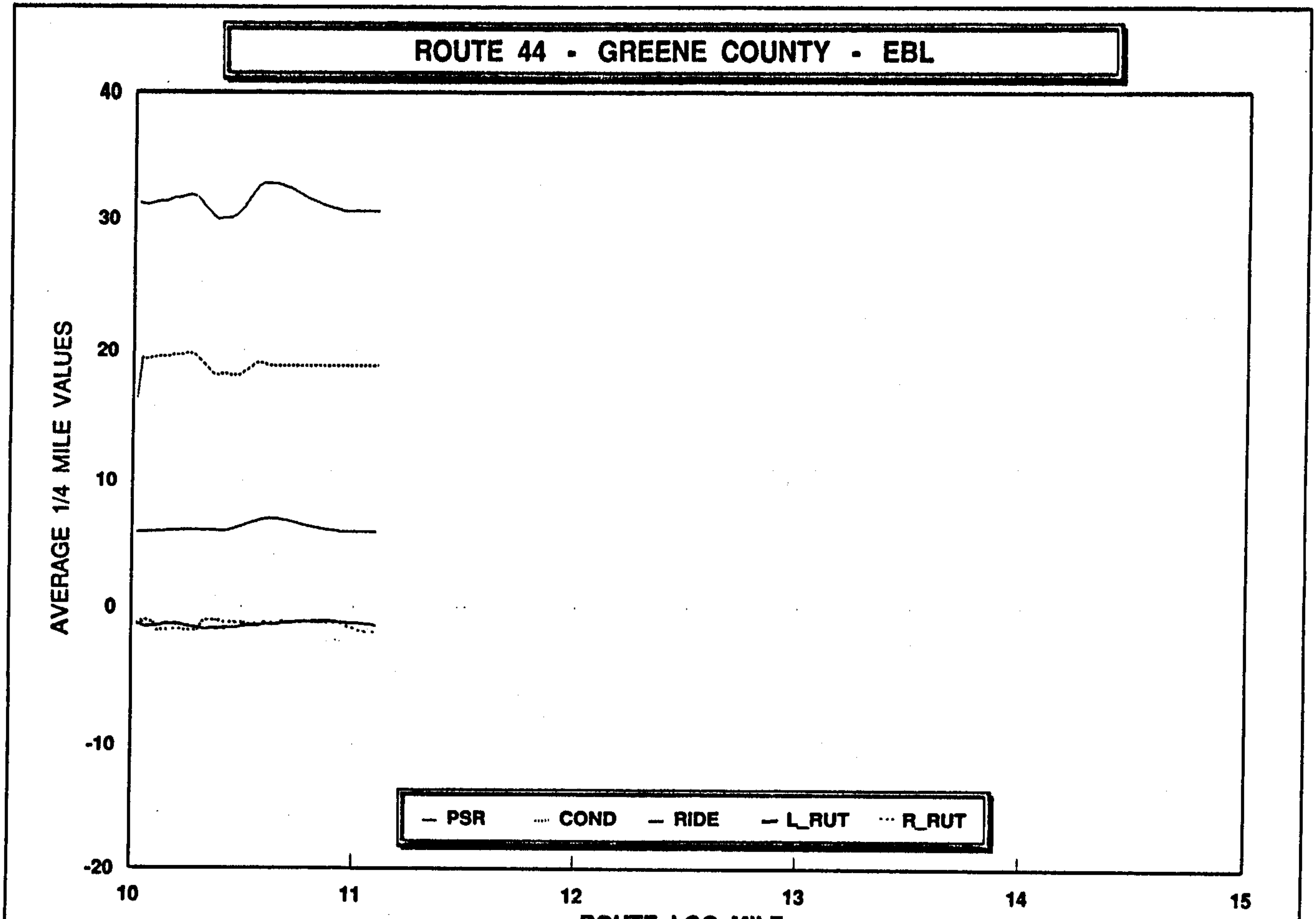

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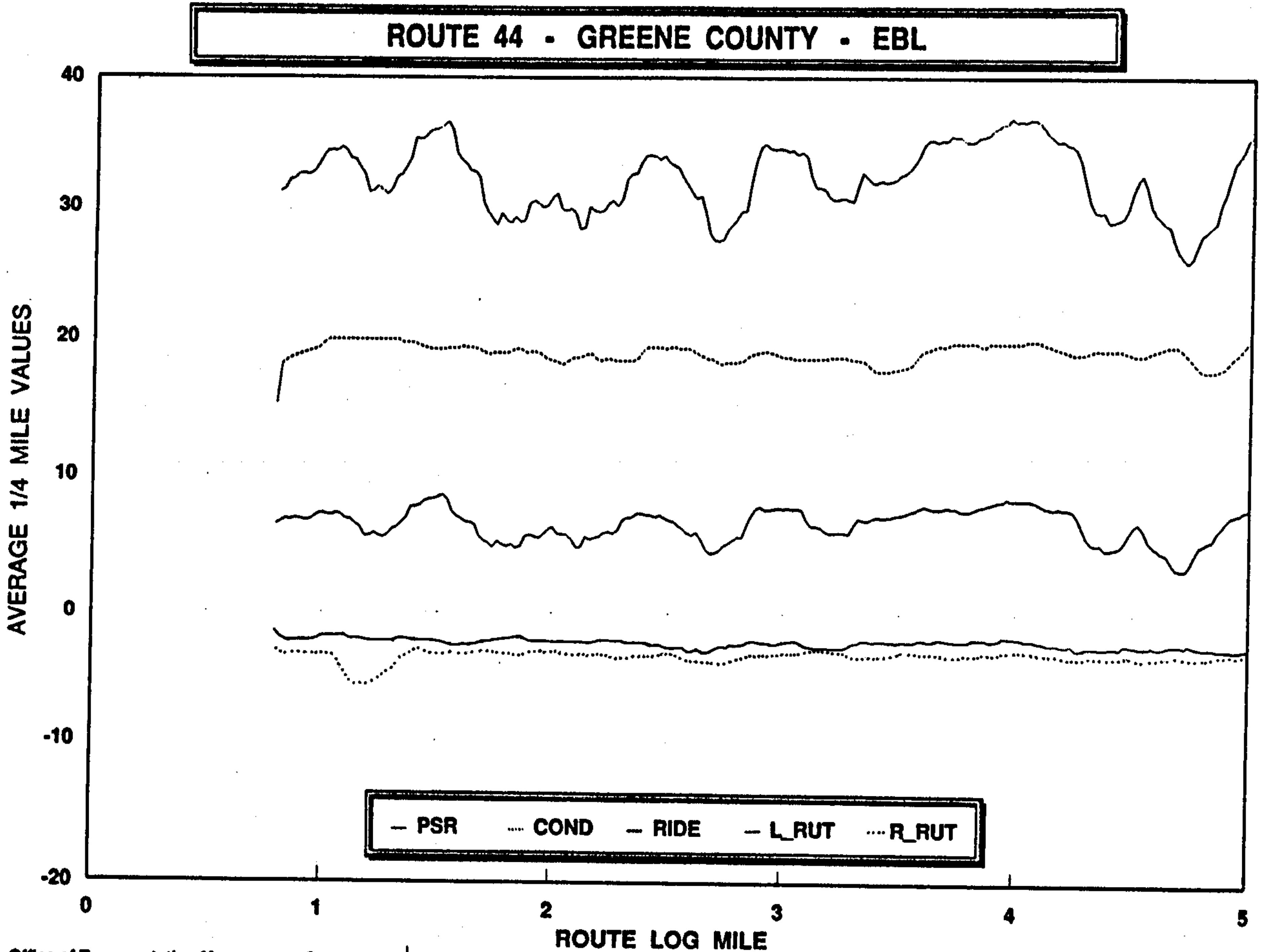

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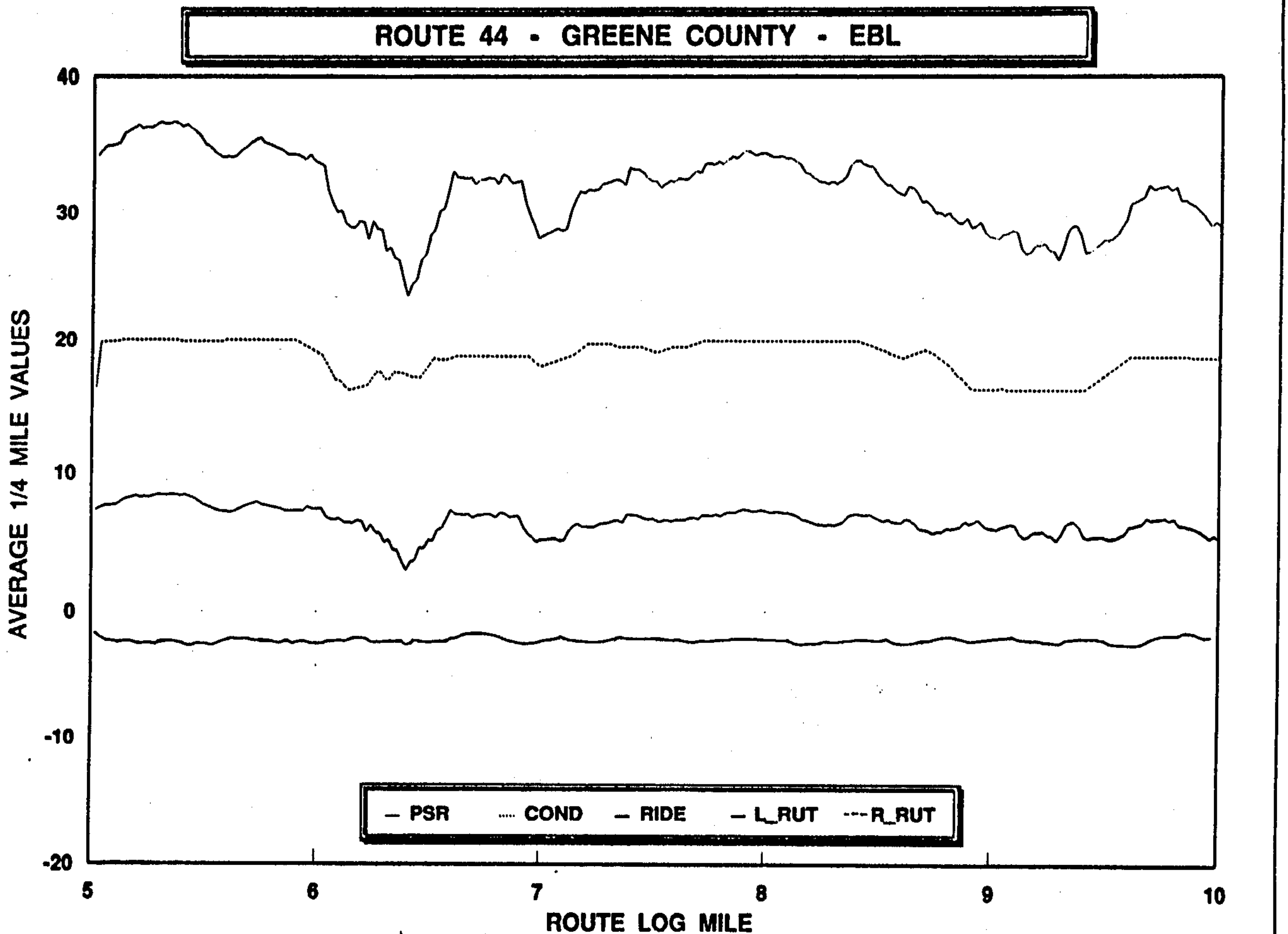

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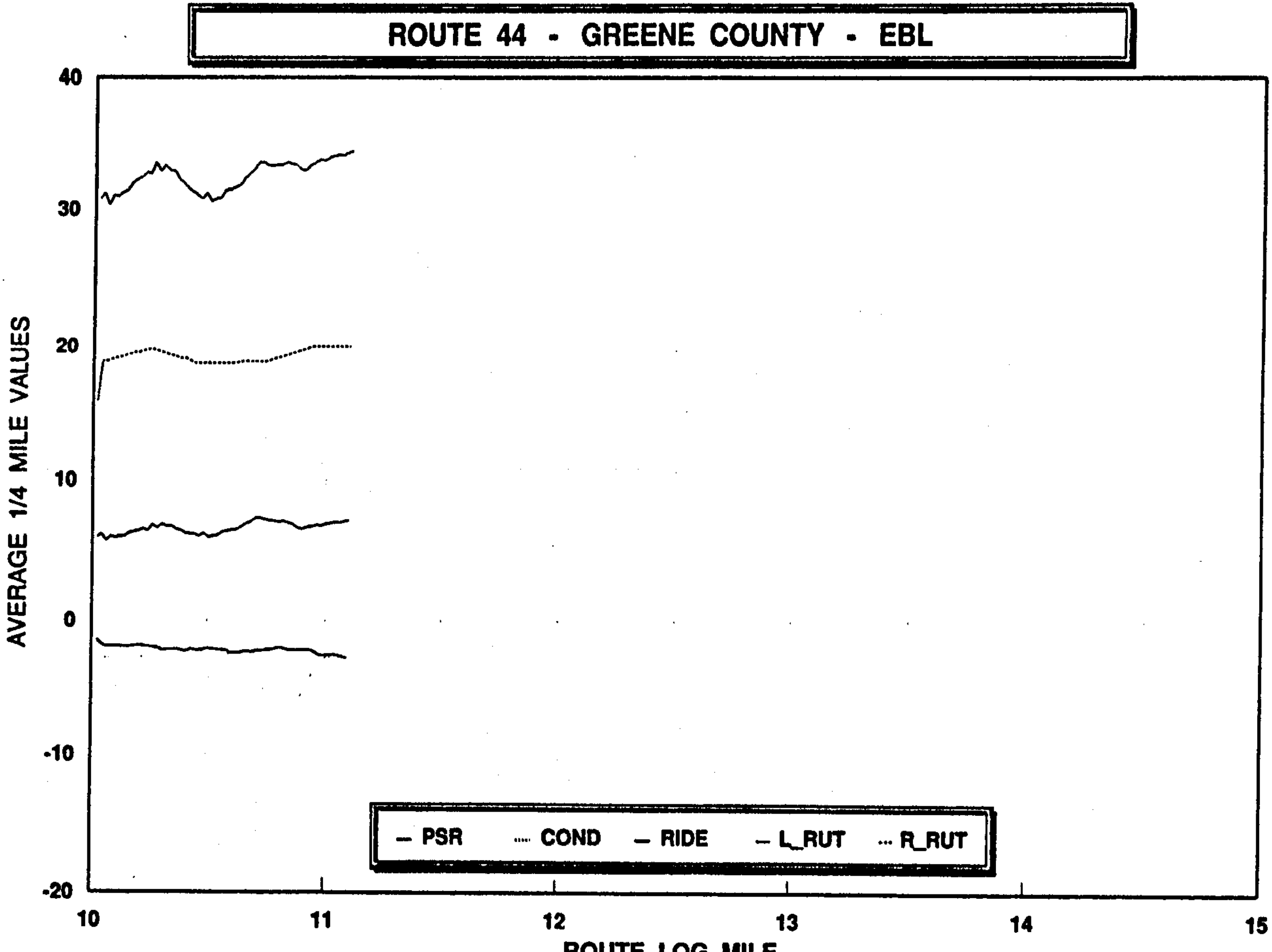

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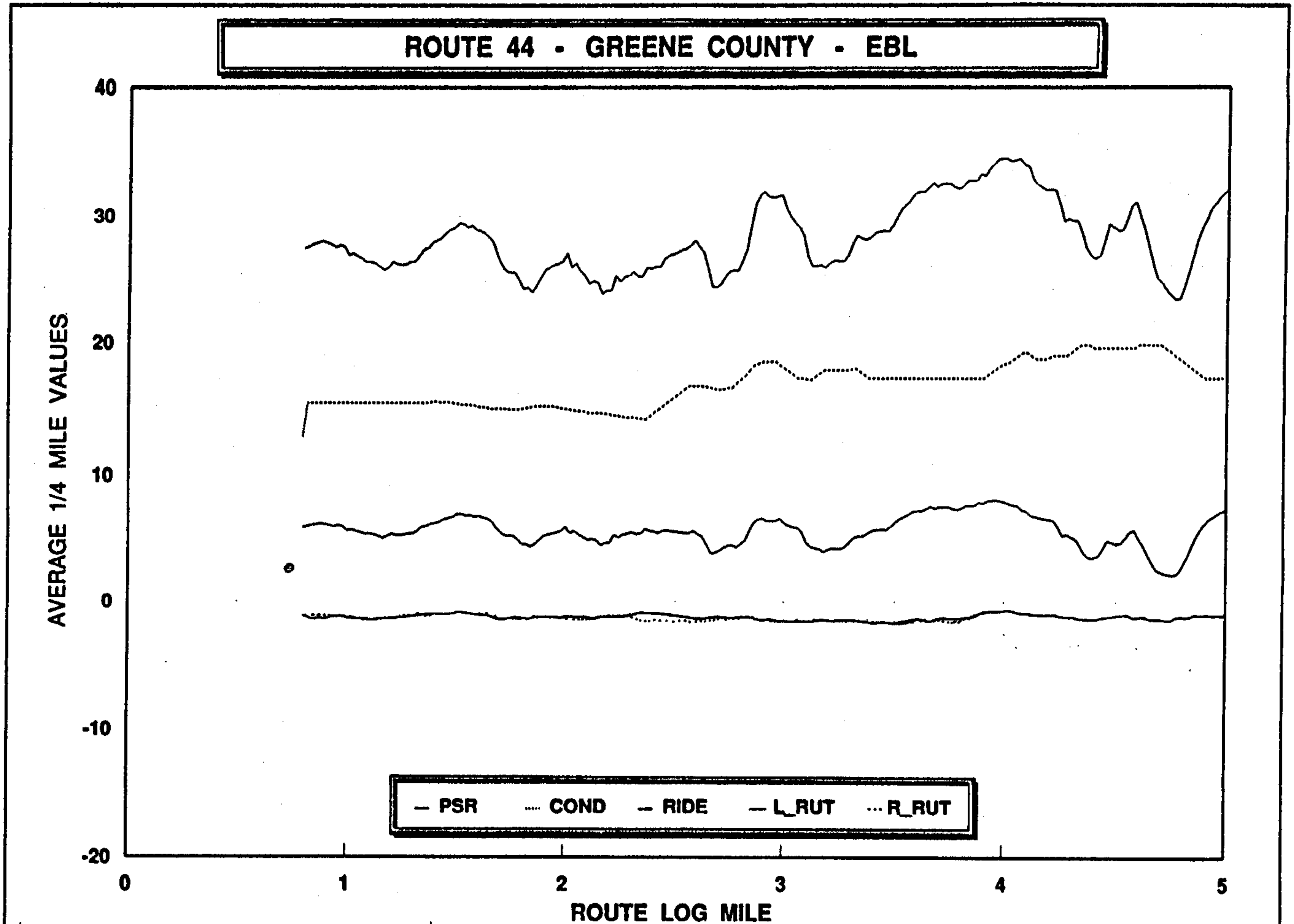

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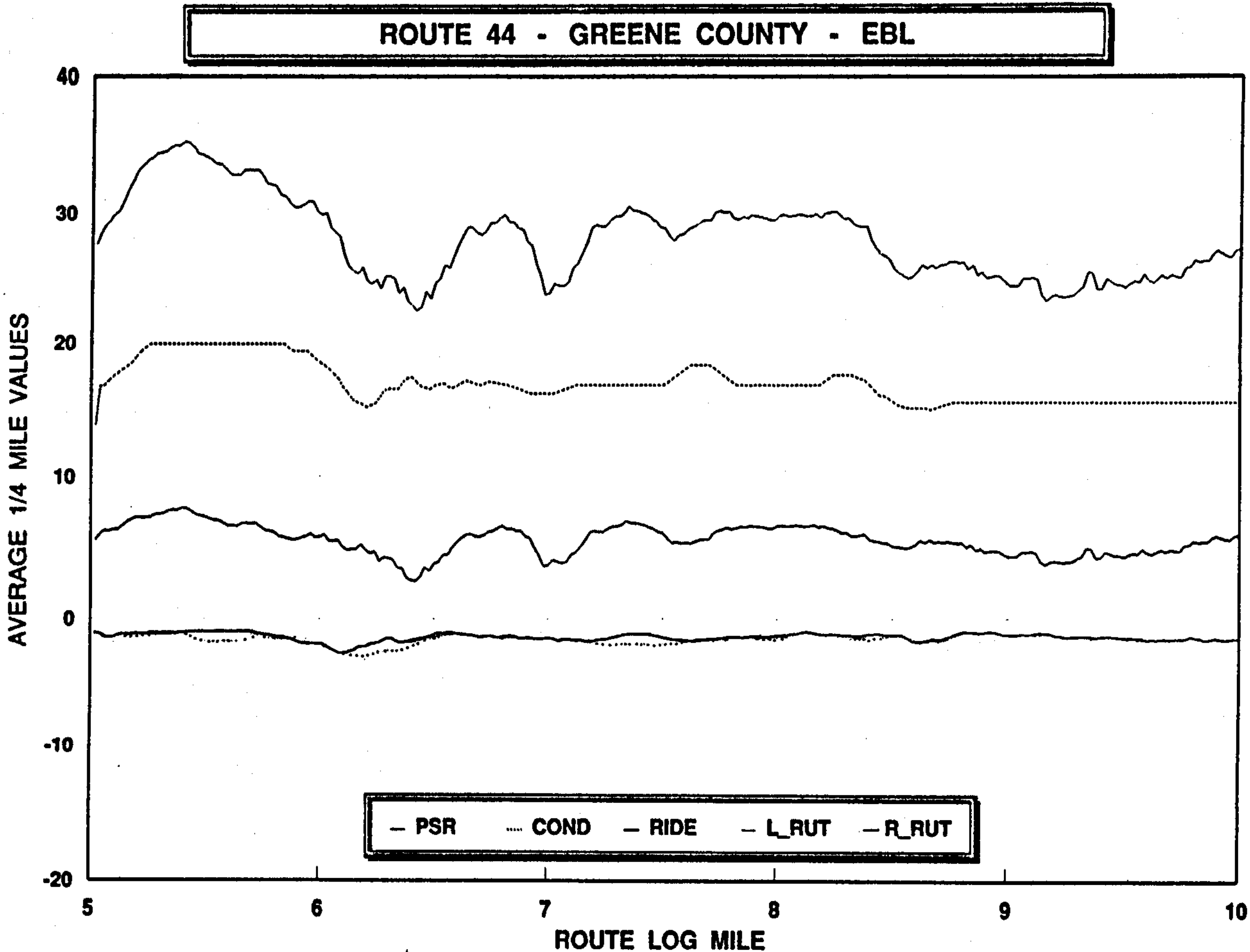

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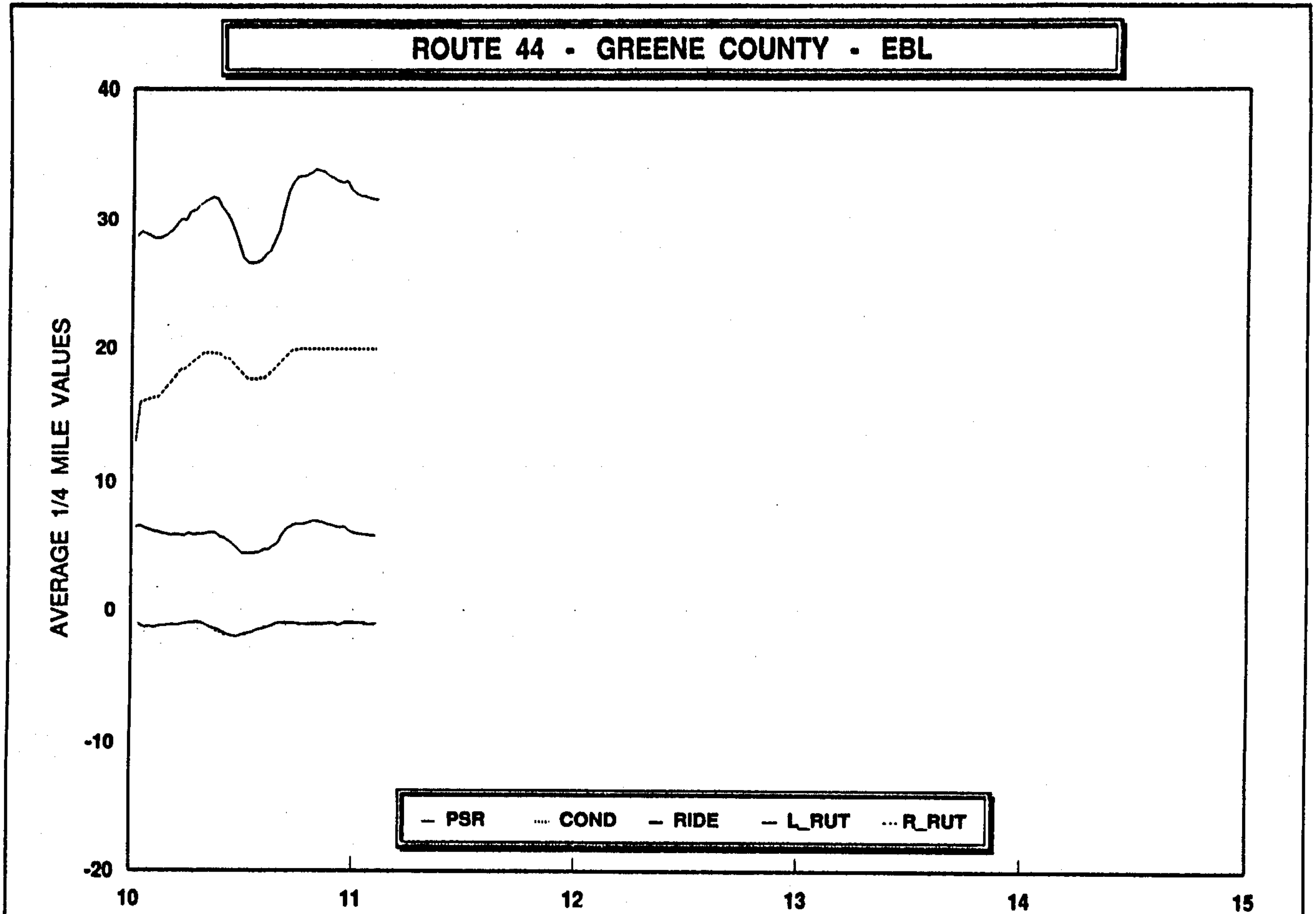

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