2002-35

Final Report

The Effect of Centerline Treatments on Driving Performance

Research

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
MN/RC – 2002-35		

4. Title and Subtitle	5. Report Date
THE EFFECT OF CENTERLINE TREATMENTS ON DRIVING PERFORMANCE	March 2002
	6.

7. Author(s)	8. Performing Organization Report No.
Kathleen Harder, John Carmody and John Bloomfield	

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
University of Minnesota College of Architecture and Landscape Architecture 1425 University Ave. SE Minneapolis, Minnesota 55405	11. Contract (C) or Grant (G) No. c) 74708 wo) 118

12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Minnesota Department of Transportation Research Services Section 395 John Ireland Boulevard, Mail Stop 330 St. Paul, Minnesota 55155	Final Report 2002
	14. Sponsoring Agency Code

15. Supplementary Notes

http://www.lrrb.gen.mn.us/PDF/200235.pdf

16. Abstract (Limit: 200 words)

In pursuit of unimpeded high peak traffic flow, the *Design Guidelines for Super Two Highways* (Ekern, 1998) suggested several treatments for the right side of roadway. But the left side is where drivers experience great speed-differentials between their own vehicles and oncoming traffic.

Harder, Carmody, and Bloomfield examined centerline treatments and possible recommendations for Super Two guidelines. The current US standard (12-foot lane / 4-inch dashes) was compared with combinations of wider lanes, wider dashes, and buffer areas.

With each of the centerline treatments examined, participants kept the left side of the vehicle in the approximate center of the lane. All treatments resulted in shifting the center of the lane farther from the centerline than it was in the standard condition.

Two conditions appear to be most effective in keeping drivers away from the centerline:
1) 14-foot lanes with both longitudinal rumble strips and 4-inch wide dashes marking the centerline, and 2) 12-foot lanes with 4-foot buffer marked by 4-inch wide dashes.
However, implementing any of the centerline treatments should result in vehicles driving farther from the centerline, thus making it less likely that drivers will meet an oncoming vehicle.

Data was gathered in a driving simulator. Further testing should be conducted in real driving situations.

17. Document Analysis/Descriptors		18.Availability Statement
Centerline treatments Driving performance	Rumble strips Super Two buffer	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	168	

The Effect of Centerline Treatments on Driving Performance

Final Report

Prepared by

Kathleen A. Harder, Ph.D.
Program for Interdisciplinary Human Factors Research in Simulation and Transportation
Department of Mechanical Engineering
Institute of Technology
and
Center for Sustainable Building Research
College of Architecture and Landscape Architecture
University of Minnesota

John C. Carmody, M.Arch.
Center for Sustainable Building Research
College of Architecture and Landscape Architecture
University of Minnesota

John Bloomfield, Ph.D
Program for Interdisciplinary Human Factors Research in Simulation and Transportation
Department of Mechanical Engineering
Institute of Technology
and
Center for Sustainable Building Research
College of Architecture and Landscape Architecture
University of Minnesota
and
Institute for Behavioural Sciences
University of Derby, UK

March 2002

Published by
Minnesota Department of Transportation
Office of Research and Strategic Services
Transportation Building, Mail Stop 330
395 John Ireland Boulevard
Saint Paul, Minnesota 55155

Acknowledgements

The authors would like to thank the following individuals and organizations for their contributions to this document.

Technical Advisory Committee

Ron Erickson, State Geometrics Engineer, Minnesota Department of Transportation
Gary Dirlam, District Traffic Engineer, District Three-Baxter, Mn/DOT
Larry Filter, Preliminary Design Engineer, District Seven-Mankato, Mn/DOT
Mark Flygare, District Traffic Engineer, District Seven- Mankato, Mn/DOT
Jon Henslin, District Traffic Engineer, District Eight-Wilmar, Mn/DOT
Dave Kopacz, Federal Highway Administration
Tom Campbell, Asst. State Traffic Engineer, Central Office, Mn/DOT
Loren Hill, State Traffic Safety Engineer, Central Office, Mn/DOT
Del Gerdes, Director, Office of Technical Support, Mn/DOT
Amr Jabr, Asst. Division Traffic Engineer, Metro, Mn/DOT
Alex Poletz, Retired State Geometrics Engineer, Mn/DOT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

Page

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

Page

LIST OF FIGURES

Page

LIST OF FIGURES

LIST OF FIGURES

Page

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

In 1998, Minnesota Department of Transportation (Mn/DOT) issued *Design Guidelines for Super Two Highways* (Ekern, 1998). Intended for upgrading principal arterial routes and selected minor arterial routes, the approach combines design features in order to provide unimpeded traffic flow and relatively high, peak traffic flow levels. Many of the Guidelines's improvements—e.g. flattening the slopes, and providing wide shoulders and adequate clear zones—affect the roadway to the right side of the driver. Because there was little attention to the driver's left side, where very high speed differentials are experienced, Ekern called for the investigation of experimental centerline treatments—in response, the driving simulation experiment described in this report was conducted.

The following six Centerline Treatments were investigated—

- Condition CTL, the control condition, with12-ft (3.6-meter) wide lanes and 4-inch (100-mm) wide centerline dashes, is the current US standard.
- Condition TB had 14-ft (4.2-meter) wide lanes, with 4-inch (100-mm) wide centerline dashes.
- Condition T3 had 14-ft (4.2-meter) wide lanes, with both longitudinal rumble strips and 4-inch (100-mm) wide dashes marking the centerline.
- Condition TC had two 12-ft (3.6-meter) wide lanes separated by a 4-ft (1.2-meters) wide central buffer area bounded by 4-inch (100-mm) wide dashes.
- Condition T4 had two 12-ft (3.6-meter) wide lanes separated by a 4-ft (1.2-meters) wide central buffer area bounded by longitudinal rumble strips. In addition, there were 4-inch (100-mm) centerline dashes.
- Condition T5 had two 12 ft (3.6-meter) wide lanes separated by a 4-ft (1.2-meters) wide central buffer area bounded by 8-inch (200-mm) wide dashes.

There were 18 participants, each of whom drove in six Test Trials. In each trial, the participant drove a 6.2-mile (10-km) bi-directional highway treated with one of the Centerline Treatments. The order of the trials was counterbalanced across participants. In each trial, the participant faced several different driving situations, including—

- Cruising with no traffic in the opposing lane.
- Cruising with traffic in the opposing lane.
- Following behavior, when the driver had to adjust to the speed of the car in-lane ahead.
- Attempts to overtake the car in-lane ahead.

We found that participants drove further from the centerline when they were cruising with traffic in the opposing lane than they did: (1) when they were cruising with no opposing traffic, and (2) when they were involved in following behavior. When following another vehicle, participants probably used the vehicle ahead as a point of reference, rather than using static road features as lane position referents. With regard to Centerline Treatments, participants drove further away from the centerline when the highway was treated with all five experimental Centerline Treatments than they did when driving with the control condition (the current US standard). When lane position relative to the edge of the left lane marker is considered, participants drove the same distance away from the left lane marker for the four Centerline Treatment Conditions with 12-ft (3.6-meter) wide lanes—i.e., for Condition CTL, the control condition, and for Conditions TC, T4, and T5, all of which had a central buffer area. The mean lane positions for these four Centerline Treatment conditions were between 1.7 meters and 1.85 meters, for driving situations involving "cruising when no opposing traffic was present" and "following" a vehicle in-lane ahead—indicating the participants kept the left side of the vehicle approximately in the center of the lane, for all four of these Centerline Treatments. For the remaining two Centerline Treatments—Conditions TB and T3, which both had 14-ft (4.2-meter) wide lanes—the mean lane positions were between 1.95 meters and 2.1 meters, for the same driving situations. These values also indicate that the participants kept the left side of the vehicle approximately in the center of the lane for these two Centerline Treatments as well. Pairwise analyses of the pathways driven in all Centerline Treatment combinations indicated that the participants drove significantly further away from the left lane marker for these two conditions.

Additional findings were that participants neither straddled the centerline in Treatment Conditions CTL, TB and T3, nor used the central buffer area as an extra lane in Treatment Conditions TC, T4, and T5. We found there were fewer "uneventful" trials and more attempts to overtake with Treatment Condition TC than there were with any other condition. The use of 12-ft (3.6-meter) lanes with a 4-ft (1.2-meter) wide center buffer area will inevitably move drivers further away from the centerline than will the use of 14-ft (4.2-meter) lanes. Conventional 4-inch (100 mm) dash lines are as effective as longitudinal rumble strips, and doubling the width of the dashes to 8-inch (200-mm) does not affect mean lane position.

Participants drove further away from the centerline with the five experimental Centerline Treatments than they did in the control condition (Condition CTL), for a combination of two reasons: (1) in all Centerline Treatment conditions, participants drove with the left side of the vehicle approximately in the center of the lane, and (2) with all five of the experimental Centerline Treatments the center of the lane is further away from the centerline than it is in the control condition. If any of the experimental Treatments is implemented by Mn/DOT, it should result in drivers driving pathways further away from opposing lanes and make it less likely that they would meet an oncoming vehicle. If choices among experimental Centerline conditions are made on the basis of keeping drivers further away from the centerline, then Conditions TC and T3 are likely to be the most effective. If the ability to overtake is also a factor, then Treatment Condition TC is likely to produce more overtaking attempts than the other four experimental Treatment Conditions—though it is debatable whether or not this is a beneficial attribute.

This report documents the effects of six Centerline Treatments on the driving performance of 18 participants. The results reported here and the recommendations made to use T3 and TC may be useful to Mn/DOT in upgrading its *Design Guidelines for Super 2 Highways*. However, it must be remembered that the experiment was conducted with a driving simulator, and further testing of these two alternatives should be conducted on a closed track or actual highways.

CHAPTER 1: INTRODUCTION

Minnesota Department of Transportation's (Mn/DOT) Super Two design approach for highways (*Design Guidelines for Super Two Highways*, Ekern, 1998) is recommended for the upgrade of principal arterial routes, or selected minor arterial routes. It involves the use of a combination of design features to produce unimpeded traffic flow and, therefore, to provide relatively high, peak traffic flow levels. Ekern indicated that the *Design Guidelines for Super Two Highways* were intended for highways with Design Speeds of 50 mph (80 km/h) to 68 mph (110 km/h). He also described the Typical Highway Cross-Section requirements, Passing Lane requirements, and Turn Lane and Entrance requirements for Super Two Highways.

Many improvements called for in the *Design Guidelines for Super Two Highways*—e.g. flattening the slopes, and providing wide shoulders and adequate clear zones—affect the roadway to the right side of the driver. In contrast, relatively little was suggested for the left side, where a driver might experience speed differentials of 125 mph (200 km/h) between his or her vehicle and traffic in the opposing lane. Because of this, Ekern called for the investigation of several experimental centerline treatments and, in response, the driving simulation experiment described in this report was conducted.

The centerline treatments explored in the experiment involved: (1) lane widths of both 12 ft (3.6 meters) and 14 ft (4.2 meters); (2) the use of a 4-ft (1.2 meter) central buffer area; (3) dashed lines widths of both 4 inches (100 mm) and 8 inches (200 mm); and (4) the use of longitudinal rumble strips in lieu of markings. Six combinations of these centerline treatments were tested in the simulation experiment.

There were six Test Trials for each of the 18 participants. In each trial, each participant drove a 6.2-mile (10-km) bi-directional highway treated with one of the six Centerline Treatment combinations. The order in which the centerline treatments were encountered was counterbalanced across participants—so that potential practice and fatigue effects were evenly distributed across the six treatments.

In each trial, there was a portion of the drive that involved the participant driving at cruising speed; in each trial there was also a portion where he or she was in a following situation, and had to respond to the vehicle in-lane ahead and decide whether or not to attempt to overtake that vehicle. Also in each trial, there was a portion of the drive in which there was no traffic in the opposing lane, and a portion in which opposing traffic was present.

This report documents the effects that six centerline treatments and three driving situations have on driving performance, primarily lane keeping. The results will enable the Minnesota Department of Transportation (MnDOT) to make recommendations about the use of centerline treatments and upgrade its *Design Guidelines for Super Two Highways*

CHAPTER 2: METHOD

Participants

Eighteen participants participated in this simulation experiment. Nine were female and nine male. Each participant had a valid driver's license at the time of the experiment and each was reimbursed $10 for his or her participation.

Driving Simulator

The experiment was conducted in a fixed-base wraparound simulator at the University of Minnesota. The simulator vehicle was a full-body 1990 Acura Integra RS. It was enclosed in a spherical wood and steel dome 12.5 ft (3.81 m) high at its apex with a 15.5 ft (4.72 m) internal diameter. Sensors in the vehicle detected accelerator, brake, and steering inputs from the driver. Force feedback was applied to the steering wheel through the steering column with a torque motor. The vehicle had a real-time interface.

Each participant drove the simulator vehicle in a computer-generated environment. This environment was projected, by three Proxima 9250+ projectors, onto a curved seamless 24-ft (7.32-m) by 8-ft (2.44-m) screen within the dome. This screen provided a 156-deg forward view to the driver. An SGI Onyx computer (Reality Engine 2) calculated the vehicle dynamics and generated the visual scenario. Programming for the visual scenario was carried out on MultiGen-Paradigm Vega and SGI Performer APIs. The Onyx also generated engine sounds and road noise, presenting them through a Cerwin-Vega satellite and subwoofer system, mounted in the trunk of the vehicle, and two Aura bass shakers, mounted under the front seats. Information from the Onyx was transmitted to and from the main simulator computer—a PC running Linux—via TCP/IP. The main computer processed all vehicular sensors and controllers. The interface between the main simulator computer and the vehicular hardware was a National Instruments AT-MIO-16E-10 data card.

Three miniature cameras were installed in the simulator vehicle. One camera was positioned on the rear-view mirror, and directed towards the participant's face; a second was positioned on the

B-pillar on the passenger side of the vehicle, so that it could record the participant's arm movements; while the third—a low-light camera—was mounted under the steering column and pointing down in order to record the position of the participant's feet on the accelerator and brake. The images from these three cameras—along with the central portion of the participant's forward view of the computer-generated environment—were shown in the four quadrants of a screen which the experimenter monitored while each participant drove in the various trials.

The simulated rumble strips used in this study were created by (1) manipulating the roadway surface to visually represent rumble strips, (2) programming the steering wheel to vibrate when the vehicle tire(s) made contact with the rumble strip (the steering wheel vibrated with increasing frequency as vehicle speed increased), and simultaneously by (3) emitting a sound resembling a rumble strip that was channeled through in-vehicle speakers and reinforced by the bass shakers mounted under the front seats.

Design

Centerline Treatments

The roadway investigated in this experiment was a two-lane bi-directional highway. The centerline treatment variations that were made to this highway involved either changes in the road width and the use of a central buffer area or changes in the width of the dashed line makers and the use of longitudinal rumble strips. The specific lane treatments that were of interest were as follows:

- Changes in road width—involving 12-ft (3.6-meter) lanes, 14-ft (4.2-meter) lanes, and 12-ft (3.6-meter) lanes with a 4-ft (1.2-meter) center buffer area.
- Changes in the left lane markings—involving conventional 4-inch (100 mm) white dashed lines, the use of rumble strips, and an alternate 8-inch (200-mm) dashed line.

There are nine possible combinations of these lane treatments. Each of these possible combinations is shown in Table 1. It was not possible to test all nine combinations of these elements—if they all had been tested, then the experiment would have been prohibitively costly. Table 1 also shows the six combinations that were tested.

Table 1: Experimental conditions tested

	12-ft lanes	14-ft lanes	12-ft lanes with 4-ft central buffer area
Conventional 4-inch dashes	CTL	TB	TC
Rumble strips in addition to dashes	—	T3	T4
Alternative 8-inch dashes	—	—	T5

Detailed descriptions of the six Centerline Treatment conditions that were tested follow:

- Condition CTL—the control condition—illustrated in Figure 1—which has12-ft (3.6-meter) wide lanes and 4-inch (100-mm) wide dashes marking the centerline, and which is effectively the current US standard.
- Condition TB—which is illustrated in Figure 2—has increased 14-ft (4.2-meter) wide lanes, with the same 4-inch (100-mm) wide dashes marking the centerline.
- Condition T3—which is illustrated in Figure 3—has the same increased 14-ft (4.2-meter) wide lanes, and a longitudinal rumble strip as well as 4-inch (100-mm) wide dashes marking the centerline.
- Condition TC—which is illustrated in Figure 4—has two 12-ft (3.6-meter) wide lanes, which are separated by a central buffer area that is 4 ft (1.2 meters) wide. This buffer area is bounded on both sides by 4-inch (100-mm) wide dashed lines. It should be noted that in this condition, the centerline is not marked.
- Condition T4—which is illustrated in Figure 5—also has two 12-ft (3.6-meter) wide lanes, which are separated by a central buffer area that is 4 ft (1.2 meters) wide. In this condition, the buffer area is bounded on both sides by longitudinal rumble strips. Also in the center of the central buffer area, there are 4-inch (100-mm) dashes marking the centerline.
- Condition T5—which is illustrated in Figure 6—again has lanes that are 12 ft (3.6-meter) wide, which are separated by a central buffer area that is 4-ft (1.2 meters) wide. In this condition, the buffer area is bounded on both sides by 8-inch (200-mm) wide dashed lines. It should be noted that in this condition, the centerline is not marked.

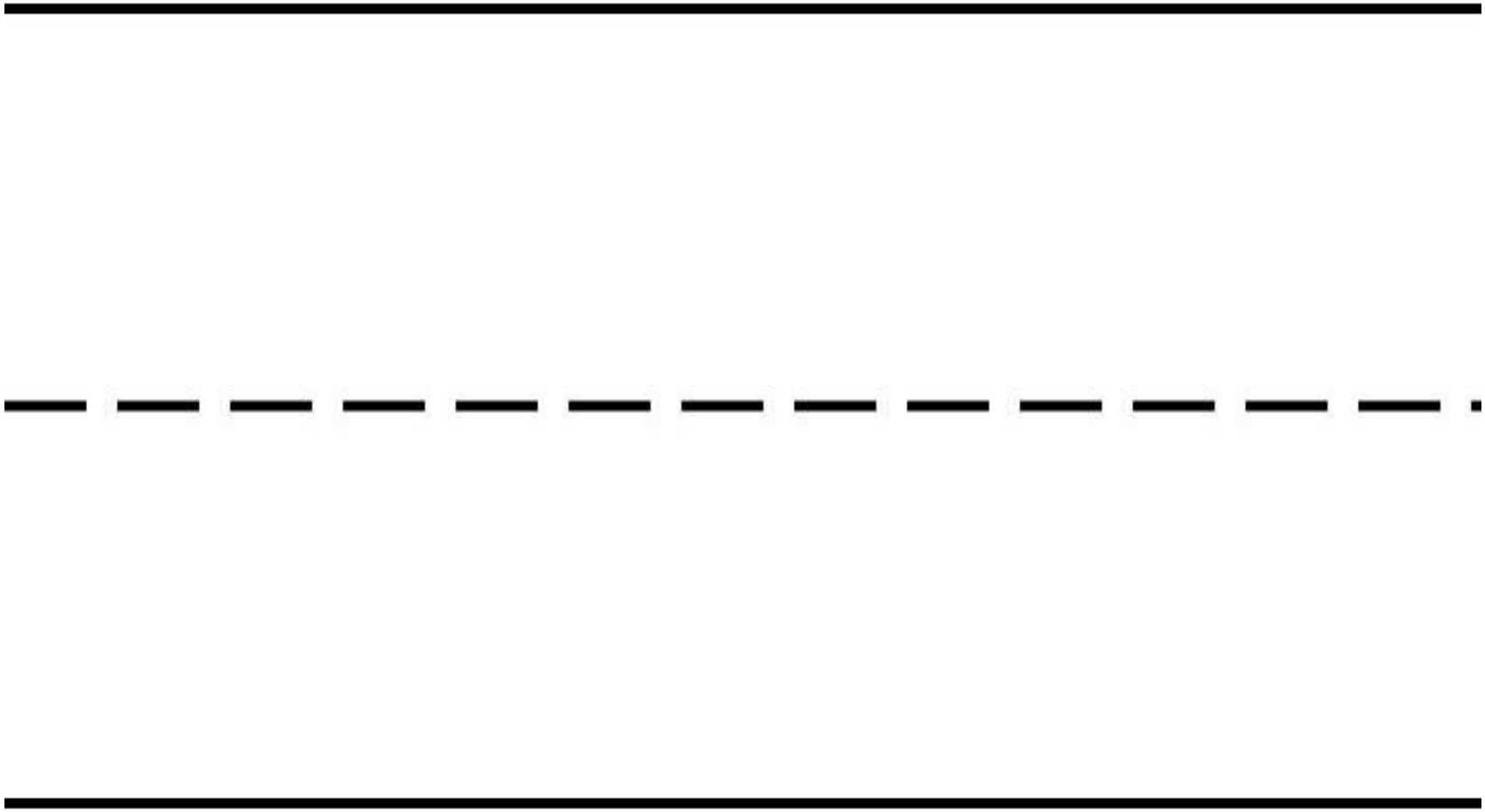

Figure 1: Condition CTL has12-ft wide lanes and 4-inch wide dashes marking the centerline.

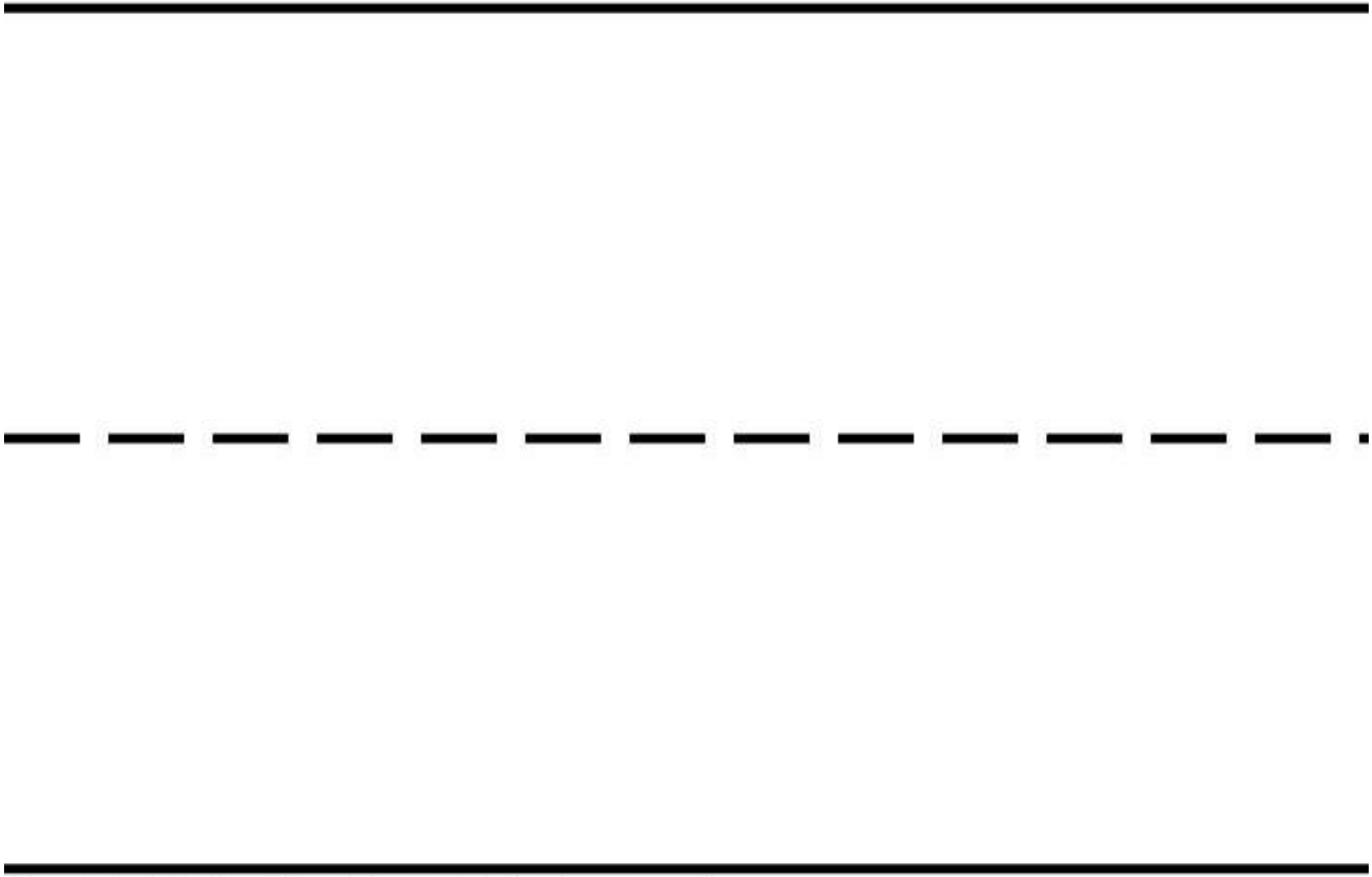

Figure 2: Condition TB has14-ft wide lanes and 4-inch wide dashes marking the centerline.

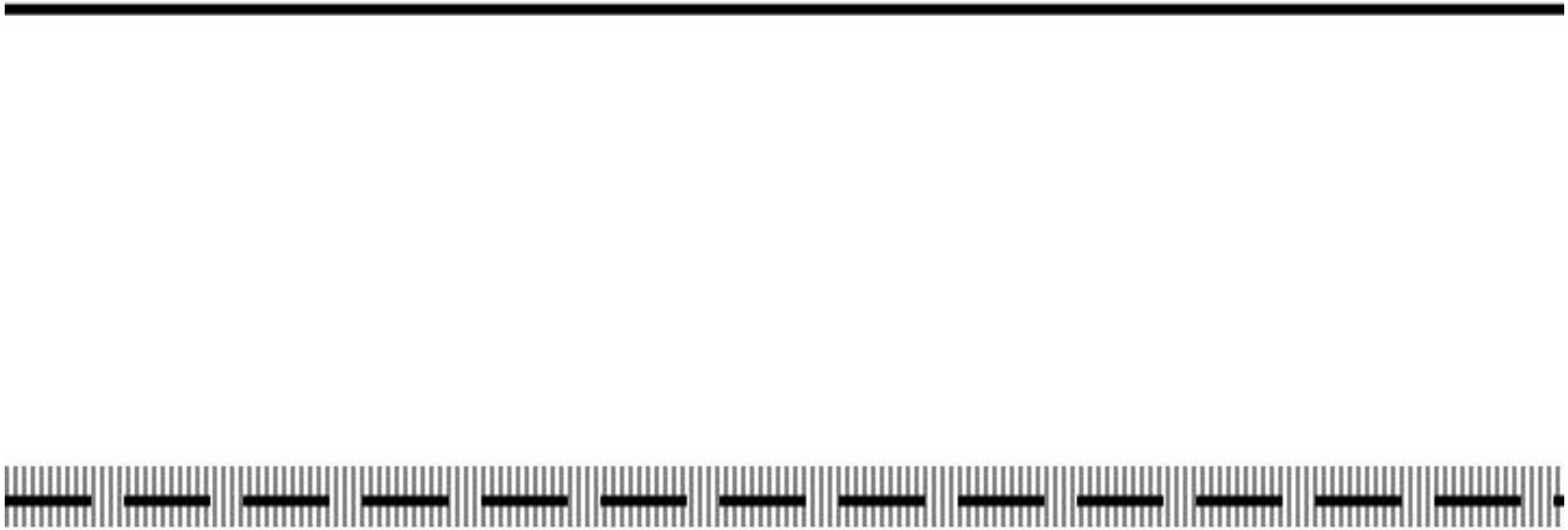

Figure 3: Condition T3 has14-ft wide lanes and a longitudinal rumble strip as well as 4-inch wide dashes marking the centerline.

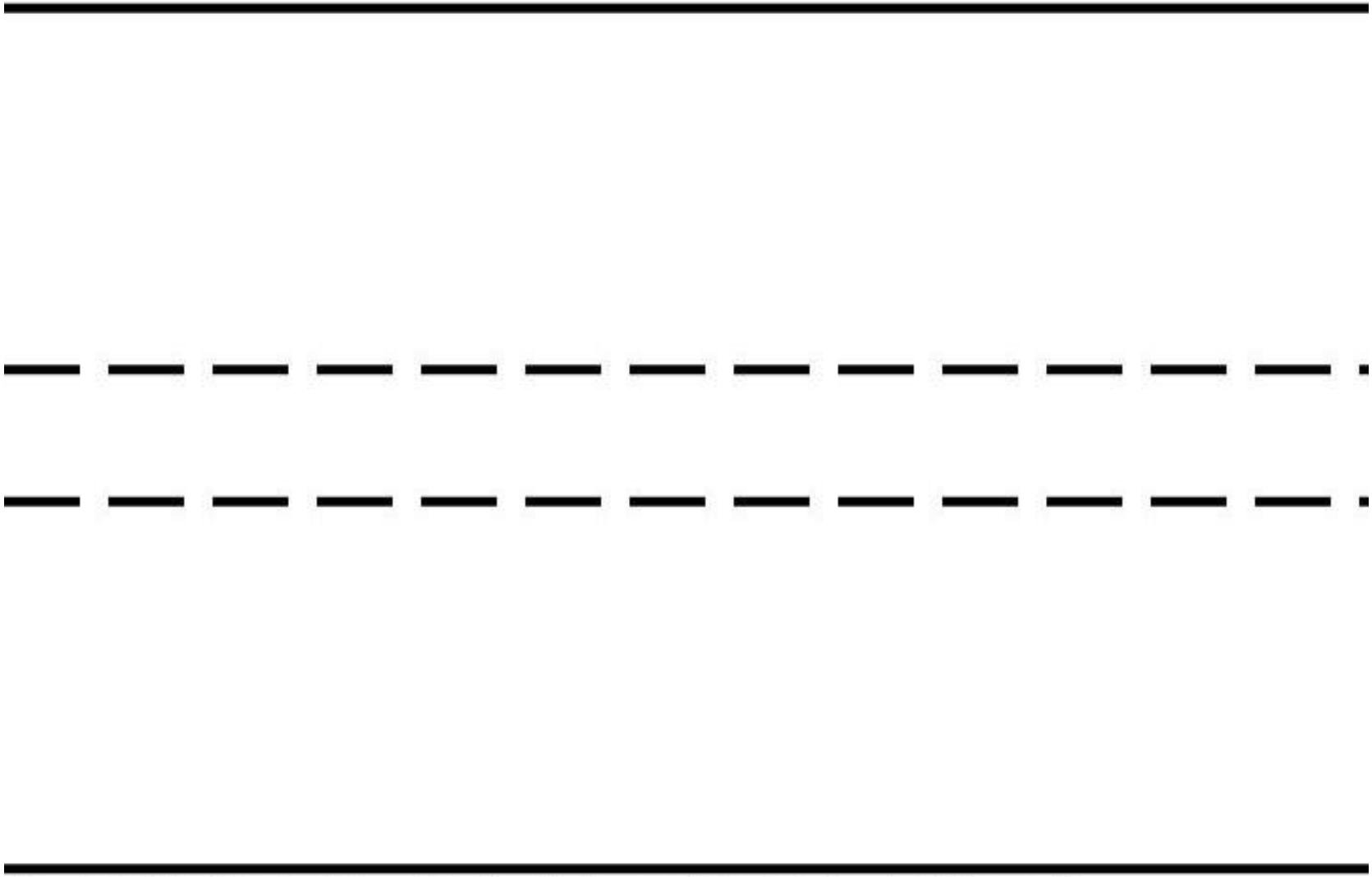

Figure 4: Condition TC has lanes that are 12-ft wide and that are separated by a 4-ft wide central buffer area. This buffer area is bounded on both sides by 4-inch wide dashed lines. The centerline is not marked.

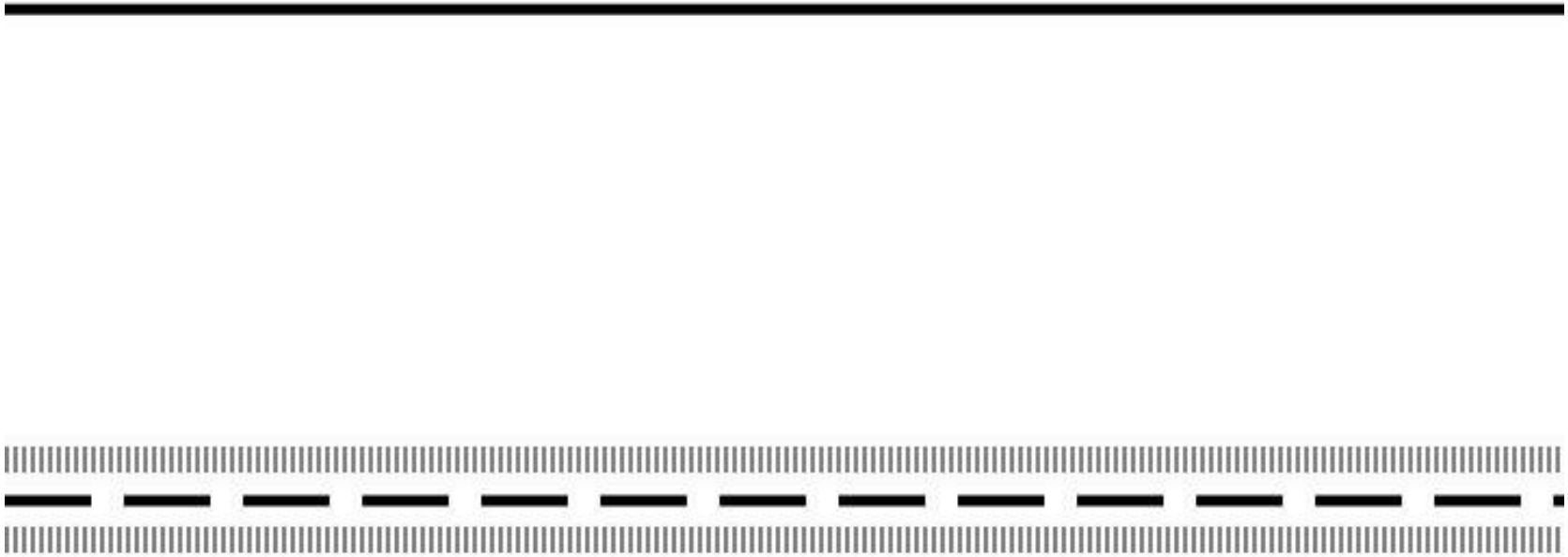

Figure 5: Condition T4 has lanes that are 12-ft wide, and separated by a central buffer area that is 4 ft in width. The buffer area is bounded on both sides by longitudinal rumble strips. Also, in the center of the central buffer area, there are 4-inch (100-mm) dashes marking the centerline.

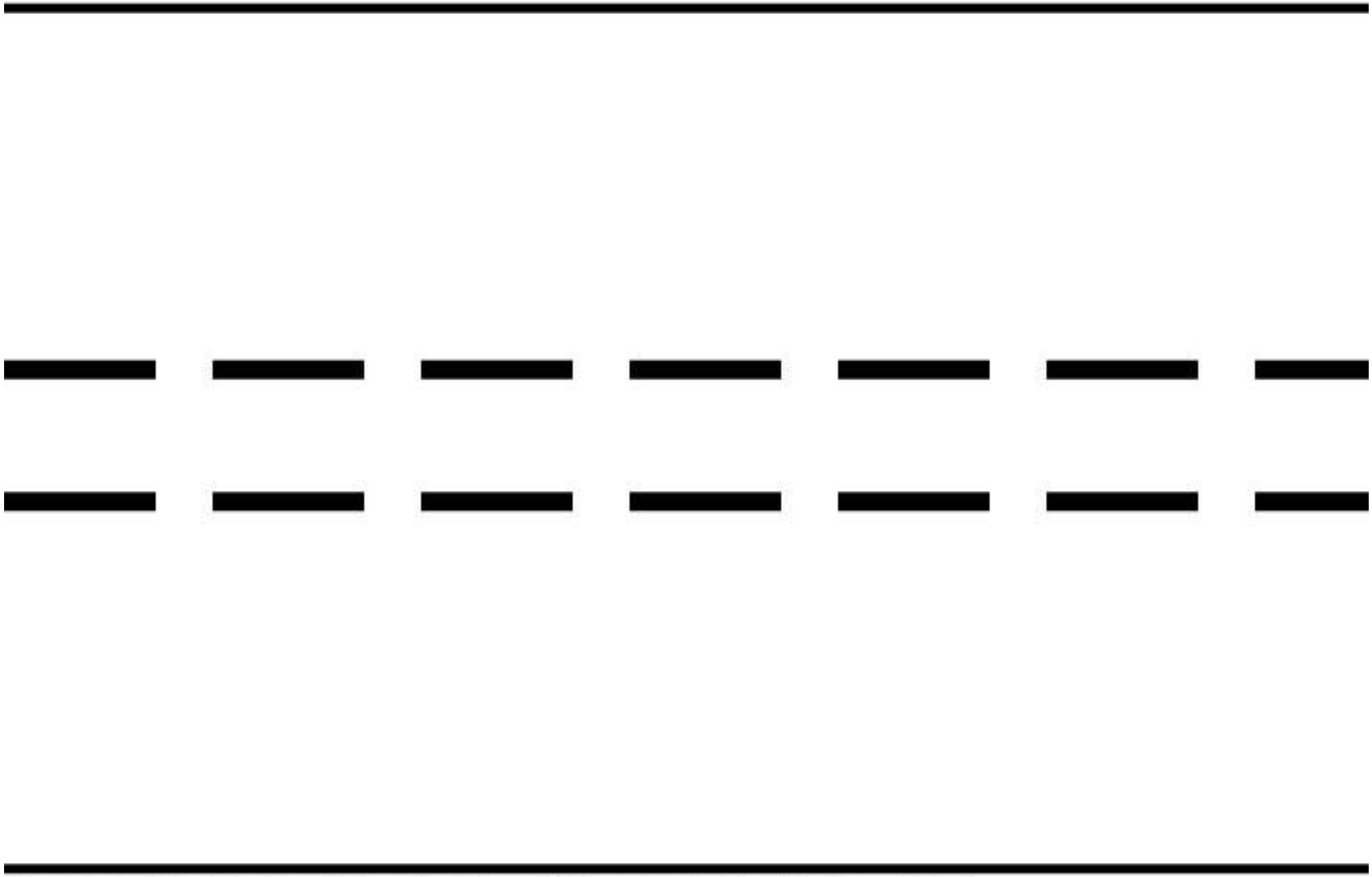

Figure 6: Condition T5 has lanes that are 12-ft wide, and that are separated by a 4-ft wide central buffer area. This buffer area is bounded on both sides by 8-inch wide dashed lines. The centerline is not marked.

Experimental Design

A within–participants experimental design was used, with each of the eighteen participants driving all six conditions. The order of presentation of the six Centerline Treatment conditions was counterbalanced across participants in such a way as to minimize practice, fatigue, and carryover effects. Table 2 shows the order in which the conditions were presented to each of the 18 participants.

Table 2: Order of presentation of the six tested Centerline Treatments

Participant	Trial #1	Trial #2	Trial #3	Trial #4	Trial #5	Trial #6
S1	CTL	TC	TB	T5	T3	T4
S2	TB	CTL	T3	TC	T4	T5
S3	T3	TB	T4	CTL	T5	TC
S4	T4	T3	T5	TB	TC	CTL
S5	T5	T4	TC	T3	CTL	TB
S6	TC	T5	CTL	T4	TB	T3
S7	T5	T3	T4	CTL	TC	TB
S8	TC	T4	T5	TB	CTL	T3
S9	CTL	T5	TC	T3	TB	T4
S10	TB	TC	CTL	T4	T3	T5
S11	T3	CTL	TB	T5	T4	TC
S12	T4	TB	T3	TC	T5	CTL
S13	T3	T4	CTL	TC	TB	T5
S14	T4	T5	TB	CTL	T3	TC
S15	T5	TC	T3	TB	T4	CTL
S16	TC	CTL	T4	T3	T5	TB
S17	CTL	TB	T5	T4	TC	T3
S18	TB	T3	TC	T5	CTL	T4

Procedure

At the beginning of each session, each participant signed a consent form. Then, seated in the simulator vehicle, he or she drove a Practice Trial in order to gain some familiarity with the way that the vehicle handled. During this trial, while the participant drove along a three-lane unidirectional highway, he or she was asked to cruise at 60 mph, to accelerate rapidly, to change lanes, and to brake rapidly to a stop.

Upon arrival at the simulator facility, each participant was assigned a participant number so that, after the Practice Trial, he or she could drive each of the six Test Trials in the order prescribed (in Table 2) for their participant number. Before driving in the Test Trials, the experimenter asked each participant to “drive as you normally would.”

In each Test Trial, the participant drove on a two-lane bi-directional highway that was approximately 6.21 miles (10 km) in length. At the start of each trial, there were three vehicles that were some way ahead of the participant's vehicle in the same lane. These three vehicles were 0.100 miles (0.161 km), 0.213 miles (0.343 km), and 0,326 miles (0.525 km) ahead of the participant's vehicle. They began to move as soon as the trial started. The vehicles traveled at 50 mph (80.5 km/hr)—a speed slow enough so that during this 6.21-mile (10-km) long trial, we expected that each participant would catch up with them. With regard to the opposing lane, at the beginning of the drive there were no vehicles in that lane. However, opposing vehicles began to appear in the opposing lane by the time the driver caught up with the closest of the vehicles that were in-lane ahead. In each trial, the driver was likely to experience most, if not all, of the following six driving situations.

- Acceleration from zero to cruising speed (this always occurred for all participants).
- Cruising with no traffic in the opposing lane (this also always occurred for all participants).
- Cruising with traffic in the opposing lane (this occurred unless the participant drove so fast that he or she caught up to the vehicles in-lane ahead before the opposing traffic arrived).
- Deceleration from cruising speed to approximately 50 mph (80.5 km/hr)—the speed of the three vehicles in-lane ahead (this always occurred—in this experiment, there was no participant who drove so slowly that he or she failed to catch up to the vehicles in-lane ahead).
- Following behavior, when the driver adjusted his or her speed to match that of the car in-lane ahead (this always occurred—as just mentioned, there was no participant who drove so slowly that he or she failed to catch up to the vehicles in-lane ahead, in this experiment).
- Attempts to overtake the car in-lane ahead (there were attempts in some trials for some participants—there were also trials in which the participants made no attempt to overtake the vehicle ahead, even though in all the experimental trials the participants did catch up to the vehicle ahead).

After driving in all six Test Trials, each participant was debriefed and paid for participating in the experiment.

CHAPTER 3: RESULTS

Lane Position

Note that *lane position in reference to the left edge of the simulator vehicle* is what is meant by "lane position" throughout this report.

In this experiment, our primary interest was on the effect that the six Centerline Treatments might have on driving performance. However, because a realistic driving scenario was used for the experiment, there are a number of other factors related to the driving situation that, in addition, may have affected the driving performance of the participants. The possible effects of these driving situation factors are discussed first.

The Effects of Centerline Treatments and Driving Situations on Mean Lane Positions Relative to the Centerline

Six driving situations that the participant could potentially experience were listed in the Procedure subsection of the Method section above. Three of them have considerable effects on lane keeping. One that does not affect lane keeping—attempts to overtake the car in-lane ahead—deals with the way in which a driver moves completely or partially out of lane; it does not affect how a driver performs the lane-keeping task and is dealt with in a later subsection. Two of the other driving situations—acceleration from zero to cruising speed and deceleration from cruising speed to the speed of the vehicle ahead—are typically of short duration and had relatively little impact on lane position over the 6.21-mile (10-km) long trial. Because of this, they were not included in the analysis of the effects of driving situation on lane position.

The three driving situations that do have a considerable influence on lane position are as follows:

- Cruising with no traffic in the opposing lane. (This situation was experienced by all participants.)
- Cruising with traffic in the opposing lane. (This situation was not experienced by some participants in some conditions—when they drove so fast that they caught up to the vehicles ahead before the opposing traffic arrived.)

- Following behavior, when the driver adjusted his or her speed to match that of the car in-lane ahead. (This situation was experienced by all participants.)

The effects of these driving situations, and the way in which they interacted with the Centerline Treatments, were explored in a two-way analysis of variance (ANOVA). The data used in this ANOVA came from eight participants rather than 18. For eight participants, there was at least one trial in which the participant drove fast enough to catch the vehicles in-lane ahead before the following behavior began; when this occurred, there was a data void for that trial, and we did not use any of that participant's data in the ANOVA. In addition, there were data collection problems in one trial for two participants—for S16 the data for Condition TC were unavailable, and similarly for S18 the data for Condition T5 were unavailable. The differences between the lane position means for all participants and for the subset included in the ANOVA are shown in Table 3.

As Table 3 illustrates, the mean lane positions were very similar in all eighteen driving situation/Centerline Treatments combinations—the differences in mean lane position ranged from 0.004 for the combination of Centerline Treatment condition TB and the Following driving situation, to 0.084 (which is a difference of 3.8 %) for the combination

Table 3. Comparison of mean lane position for all participants with mean lane position of participants included in ANOVA for—
(a) Cruising with no traffic in opposing lane.

Lane treatment condition	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5
Overall mean lane position (and number of participants)	1.826 (17)	2.124 (16)	2.169 (17)	2.438 (15)	2.302 (17)	2.220 (15)
Means used in ANOVA (for 8 participants)	1.798	2.101	2.131	2.383	2.351	2.194

(b) Cruising when there was traffic in opposing lane.

Lane treatment condition	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5
Overall mean lane position (and number of participants)	2.110 (12)	2.286 (16)	2.438 (15)	2.547 (12)	2.488 (14)	2.316 (12)
ANOVA mean (for 8 participants)	2.121	2.216	2.422	2.489	2.434	2.322

(c) Following driving situation.

Lane treatment condition	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5
Overall mean lane position (and number of participants)	1.883 (16)	2.100 (16)	2.191 (16)	2.349 (15)	2.334 (17)	2.217 (15)
ANOVA mean (for 8 participants)	1.899	2.104	2.275	2.373	2.373	2.257

of Centerline Treatment condition T3 and the Following driving situation. Since the differences were very small (never more than 3.8 %), it can be assumed that the subset of participants whose data were used in the ANOVA were representative of the whole group. Table 4 presents the summary of the two-way ANOVA examining the effects of driving situations and the lane treatments.

As Table 4 shows, both main effects of driving situation and of Centerline Treatments are statistically significant, at the p=0.002 and p<0.0001 levels, respectively. In addition, the interaction between the two main effects is significant at the p=0.0295 level. In order to illustrate these effects, mean lane position was plotted as a function of Centerline Treatment, with the result shown in Figure 7.

Table 4. Summary of analysis of variance comparing the effects of Centerline Treatments and driving situations on lane position.

Source of variance	Degrees of freedom	Sum of squares	Variance estimate	F-value	p-value
(1) Participants (S)	7	3.673	0.525		
(2) Driving situation (D)	2	0.762	0.382	9.959	0.0020
Error Term for (2) was interaction of S x D	14	0.537	0.038		
(3) Centerline treatment (C)	5	3.691	0.738	18.666	<0.0001
Error term for (3) was inter-action of S x C	35	1.384	0.040		
(4) Interaction of D x C	10	0.241	0.024	2.174	0.0295
Error term for (4) was inter-action of S x D x C	70	0.776	0.011		

First looking at the effects of the driving situations, Figure 7 shows that, over all Centerline Treatments, the participants had higher lane position means—i.e., drove further from the centerline—when they were cruising and there was traffic present in the opposing lane than in the other two driving situations (when they were cruising with no traffic in the opposing lane and when they were following a vehicle in-lane ahead).

Second looking at the effects of the Centerline Treatments, Figure 7 also shows that the participants had higher lane position means (drove further from the centerline) for all but one of the Centerline Treatment conditions—the exception was Centerline Treatment Condition CTL, the control condition, with which they drove closer to the centerline. When the five experimental Centerline Treatments are considered alone, the participants had higher lane position means (drove further from the centerline) for Conditions TC and T4 than they did for Condition TB.

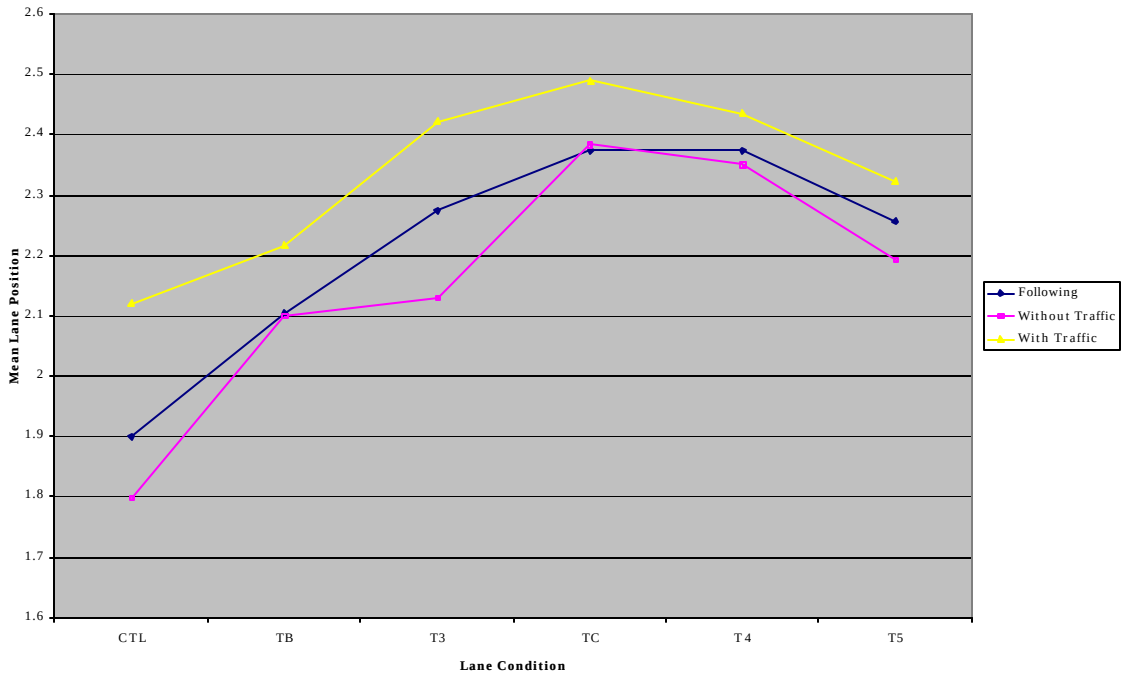

Figure 7: Mean lane position relative to the centerline (for the data used in the ANOVA) as a function of Centerline Treatment condition for the three driving situations. [The larger the mean lane position, the further away from the centerline the participant drove.]

Third, considering the interaction effect, Figure 7 indicates two possible reasons for its occurrence. The first, and more likely reason for its occurrence, is because the difference between the lane position means for the driving situation in which the participants were cruising, with traffic present in the opposing lane, and the other two driving situations (when they were cruising with no traffic in the opposing lane and when they were following a vehicle in-lane ahead) was greater for Centerline Treatment Conditions CTL and T3, than it was for Conditions TC, T3, and T5. The second possible reason for the interaction was that, for Centerline Treatment Condition T3, there was a difference between the driving situation in which the participants were cruising with no traffic in the opposing lane and the driving situation in which they were following a vehicle in-lane ahead, whereas for the other five Centerline Treatments there was no difference between these two driving situations.

As already mentioned, the ANOVA was conducted with data from only eight of the participants. Table 3 suggests that there was a negligible difference in mean lane positions for the ANOVA

subgroup and in those for all 18 participants together. As a further check on this suggestion, Figure 8 presents mean lane position—using data from all 18 participants—as a function of Centerline Treatment condition for the three driving situations.

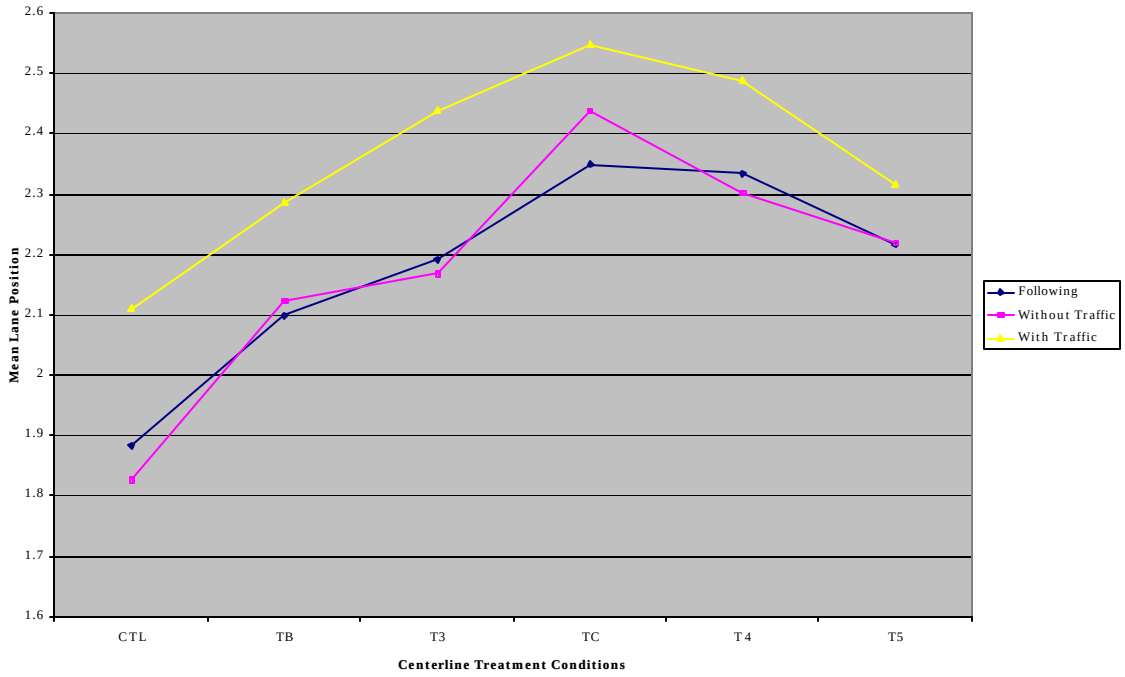

Figure 8: Mean lane position relative to the centerline (using data from all 18 participants) as a function of Centerline Treatment condition for the three driving situations. [The larger the mean lane position, the further away from the centerline the participant drove.]

Observation of Figure 8 confirms the comments—about the effects of both the driving situations and the Centerline Treatment—that were made based on Figure 7. The comments regarded the effects of the driving situations, over all Centerline Treatments, the participants had higher lane position means—i.e., drove further from the centerline—when they were cruising and there was traffic present in the opposing lane than in the other two driving situations (when they were cruising with no traffic in the opposing lane and when they were following a vehicle in-lane ahead). Also, with regard to the effects of the Centerline Treatments, the participants had higher lane position means (drove further from the centerline) for all but one of the Centerline Treatment conditions—with the exception, as with Figure 7, being for Centerline Treatment Condition CTL with which they drove closer to the centerline. And when the five experimental Centerline Treatments are considered alone, also as before, the participants had higher lane

position means (drove closer to the centerline) for Conditions TC and T4 than they did for Condition TB.

As far as the interaction effect is concerned, Figures 7 and 8 are similar with regard to the first and more likely of the reasons for its occurrence—i.e., that it occurred because the difference between the lane position means for the driving situation in which the participants were cruising and there was traffic present in the opposing lane, and the other two driving situations (when they were cruising with no traffic in the opposing lane and when they were following a vehicle in-lane ahead) was greater for Centerline Treatment Conditions CTL and T3, than it was for Conditions TC, T3, and T5.

With regard to the second possible reason for the interaction, observation of Figure 8 does not confirm the possibility. While Figure 8 shows that there was a small difference between the driving situation in which the participants were cruising with no traffic in the opposing lane and the driving situation in which they were following a vehicle in-lane ahead, the Centerline Treatment Condition in which that may occur is Condition TC—not Condition T3, as it was for Figure 7. Because of this, the second possible reason for the interaction will not be considered any further.

The comparison between Figures 7 and 8 confirms the assumption we made based on Table 3, that the subset of participants used in the ANOVA were representative of the larger group of 18 participants who participated in the experiment.

The Effects of Centerline Treatments on Mean Lane Position Relative to the Left Lane Marker

The data presented in Figures 7 and 8 deal with the participants' mean lane position relative to the center of the highway, whether it was for Centerline Treatment Conditions CTL, TB, T3, and T4—in all of which the centerline was actually marked (although for Condition T4 the centerline was in the middle of the central buffer area, which was delineated with longitudinal rumble strips)—or for Centerline Treatment Conditions TC and T5 (in both of which the centerline was not marked). However, it is also of considerable interest to discover the mean lane position of the driver's vehicle relative to the edge of the left lane marker as they drove in each of the

Centerline Treatment conditions. Figure 9 presents this relationship of mean lane position relative to the edge of the left lane marker as a function of Centerline Treatment condition—the data used in this figure are from all 18 participants. (Because, as with Figure 7 and 8, the graph obtained for the ANOVA subset shows a similar pattern, it is not reproduced here.)

Figure 9 was derived as follows. The distances from the edge of the left lane marker were obtained by subtracting the appropriate amount (based on the particular Centerline Treatment condition) from the distances from the centerline that were already shown in Figures 7 and 8. One result of this procedure was that, within each Centerline Treatment condition, the relative effects on lane position of the three driving situations remain unchanged. However, the relative effects of the Centerline Treatments are changed by the procedure—as can be seen in Figure 9.

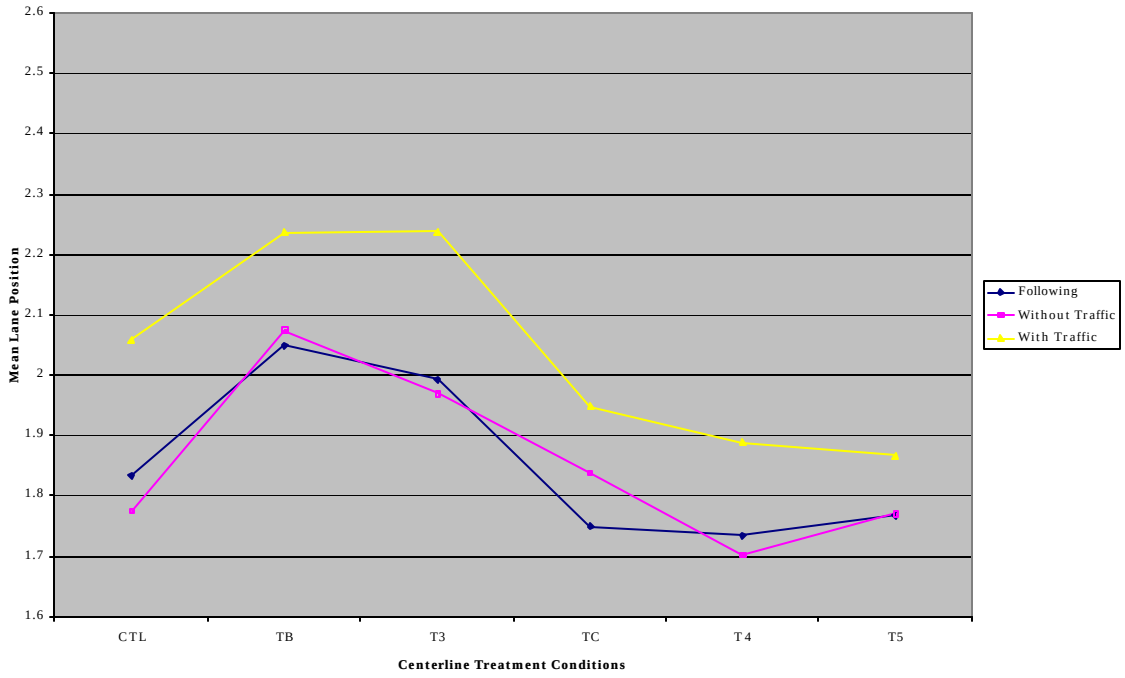

Figure 9: Mean lane position relative to the edge of the left lane marker (using data from all 18 participants) as a function of Centerline Treatment condition for the three driving situations. [The larger the mean lane position, the further away from the left lane marker the participant drove.]

As Figure 9 shows, for all three driving situations, the participants drove at approximately the same distance from the edge of the left lane marker for four of the Centerline Treatment conditions—Condition CTL, the control condition which had 12-ft (3.6-meter) wide lanes, and Conditions TC, T4, and T5, the three conditions in which two 12-ft (3.6-meter) wide lanes were

separated by a 4-ft (1.2-meter) central buffer area. Figure 9 also shows that, for the remaining two Centerline Treatments—Conditions TB and T3, both of which had 14-ft (4.2-meter) wide lanes—the participants drove further from the edge of the left lane marker than they did for the four conditions with 12-ft (3.6-meter) wide lanes. The mean lane positions for these last two conditions were similar to each other.

Overall Effect of Centerline Treatment on Lane Position Relative to the Left lane Marker

The analysis presented in the subsection above broke each trial down into sections on the basis of the different driving situations encountered by the participants during each trial. In this subsection, the overall effect of the Centerline Treatments is assessed. Lane position was plotted throughout the 10 km traveled in each of the six Test Trials driven by each of the 18 participants: the resultant plots are presented in Appendix A, as Figures A1 through A106.

Each of these figures was assessed in two ways. The first way of assessing Figures A1 through A106 involved a series of comparisons of the pathways driven in each of the six Test Trials by each of the 18 participants. The second assessment, concerning the effects of the Centerline Treatments on driving behavior is presented in the next subsection

The series of comparisons of the pathways driven in each of the six Test Trials by each of the 18 participants were made by overlaying pairs of figures on each other, adjusting them until the edge of the left lane markers were aligned. Then a judgment was made as to which pathway was closer to the edge of the left lane marker—the judgments were made in a pairwise fashion until each possible pair in the set of six figures for each participant had been examined. The pathway (or pathways) judged to be closet to the edge of the left lane marker were assigned a score of 1; the pathway(s) judged to be next closest were given a score of 2; the pathway(s) judged to be next closest were given a score of 3; and so on. The results of the pairwise judgments are shown in Table 5.

A Chi-square test was used to analyze the aggregates shown in Table 6. For the purposes of this analysis, the entries for the scores of 2, 3, and 4 were combined—producing the values shown in Table 7.

Table 5: Assessment of closeness of pathways to the left lane marker driven by each participant.

Participant	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5
S1	2	2	2	1	2	2
S2	2	3	3	1	2	2
S3	2	3	3	3	1	1
S4	1	2	2	2	1	2
S5	3	3	2	1	3	2
S6	1	1	1	1	1	1
S7	3	3	3	2	1	3
S8	2	3	4	1	2	2
S9	3	2	2	1	2	2
S10	2	2	2	1	2	2
S11	2	2	3	2	1	2
S12	1	2	1	1	1	1
S13	2	3	2	1	1	2
S14	3	3	3	1	2	1
S15	2	2	2	1	2	2
S16	2	3	2	N/A	1	2
S17	1	1	1	1	1	1
S18	1	4	3	2	2	N/A

These judgments were aggregated as shown in Table 6, which shows the number of scores of 1, 2, 3, and 4 occurring for each Centerline Treatment as well as a total score and average.

Table 6: Aggregate of closeness scores occurring for each Centerline Treatment.

Closeness scores	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5
1	5	2	3	12	9	5
2	9	7	8	4	8	11
3	4	8	6	1	1	1
4	—	1	1	—	—	—
Total	35/18	44/18	41/18	23/17	28/18	30/17
Average	1.944	2.444	2.278	1.353	1.556	1.765

Table 7: Combined aggregate closeness scores occurring for each Centerline Treatment that were used in the Chi-square analysis.

Closeness scores	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5	Totals
1	5	2	3	12	9	5	36
>2	13	16	15	5	9	12	70
Totals	18	18	18	17	18	17	106

The test resulted in chi-square=150.44, for 5 degrees of freedom, which is statistically significant at the $p<0.001$ level. The pathways occurring with Centerline Treatment Conditions TB and T3 are further away from the edge of the left lane statistically significantly more often than the

pathways occurring with conditions TC and T4. This analysis reinforces the pattern shown earlier in Figure 9, which suggests that the mean lane positions for Conditions TB and T3 are further away from the edge of the left lane than the mean lane positions for conditions TC and T4. Figure 9 also suggests that the mean lane positions for Conditions TB and T3 are further away from the edge of the left lane than the mean lane positions for Conditions CTL and T5 although these differences are smaller (which is why no statistical significance attaches to Conditions CTL and T5 in the Chi-square analysis).

Overall Effect of Centerline Treatment on Driving Behavior

The second way in which Figures A1 through A106 were assessed involved categorizing the lane keeping behavior found in each figure. The behavior was assigned to one or more of the non-exclusive categories—illustrated in Figures 10 through 14—that follow on the next five pages of this report.

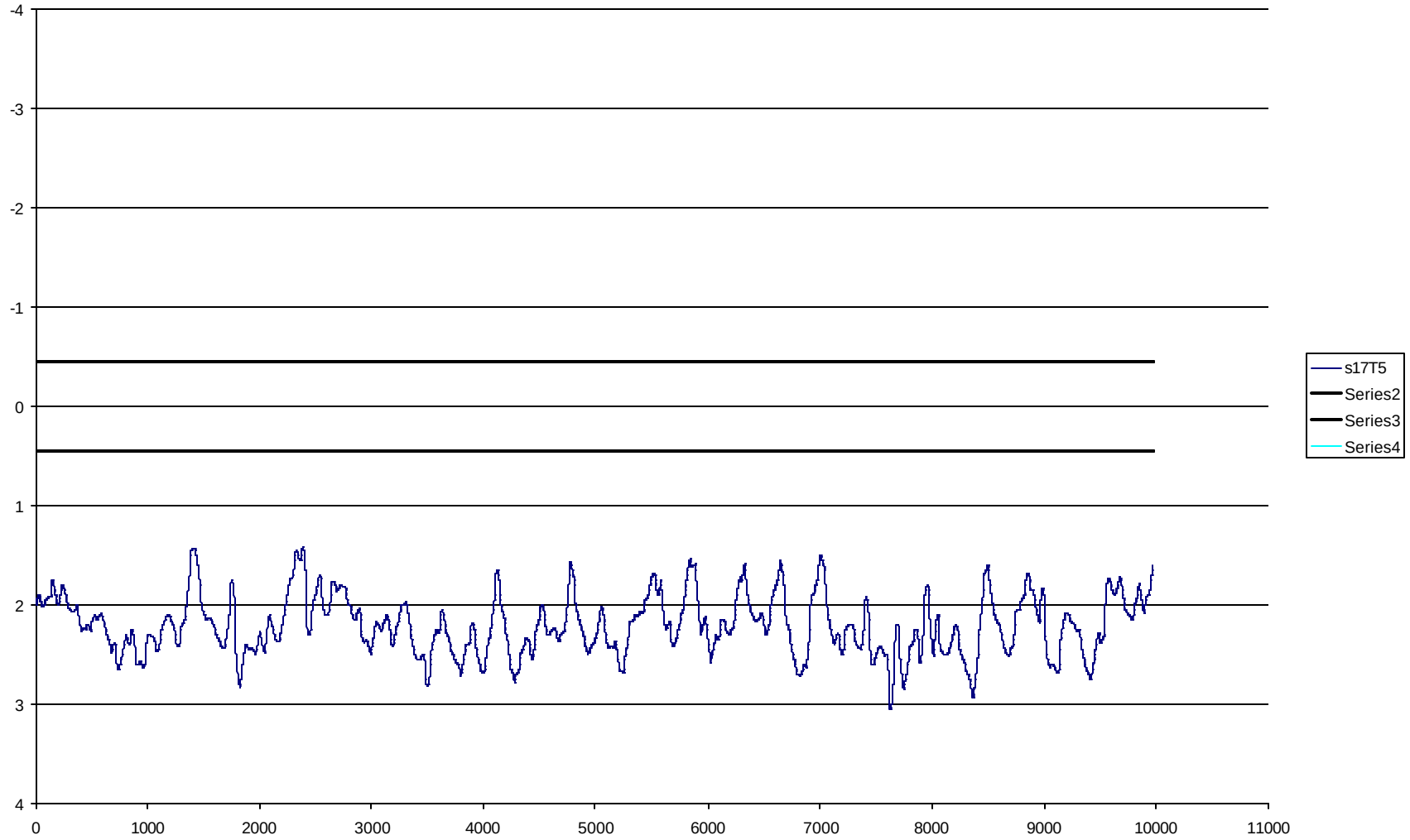

Figure 10: Example of an uneventful trial. [Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition T5. Also appears as Figure A101 in Appendix A.]

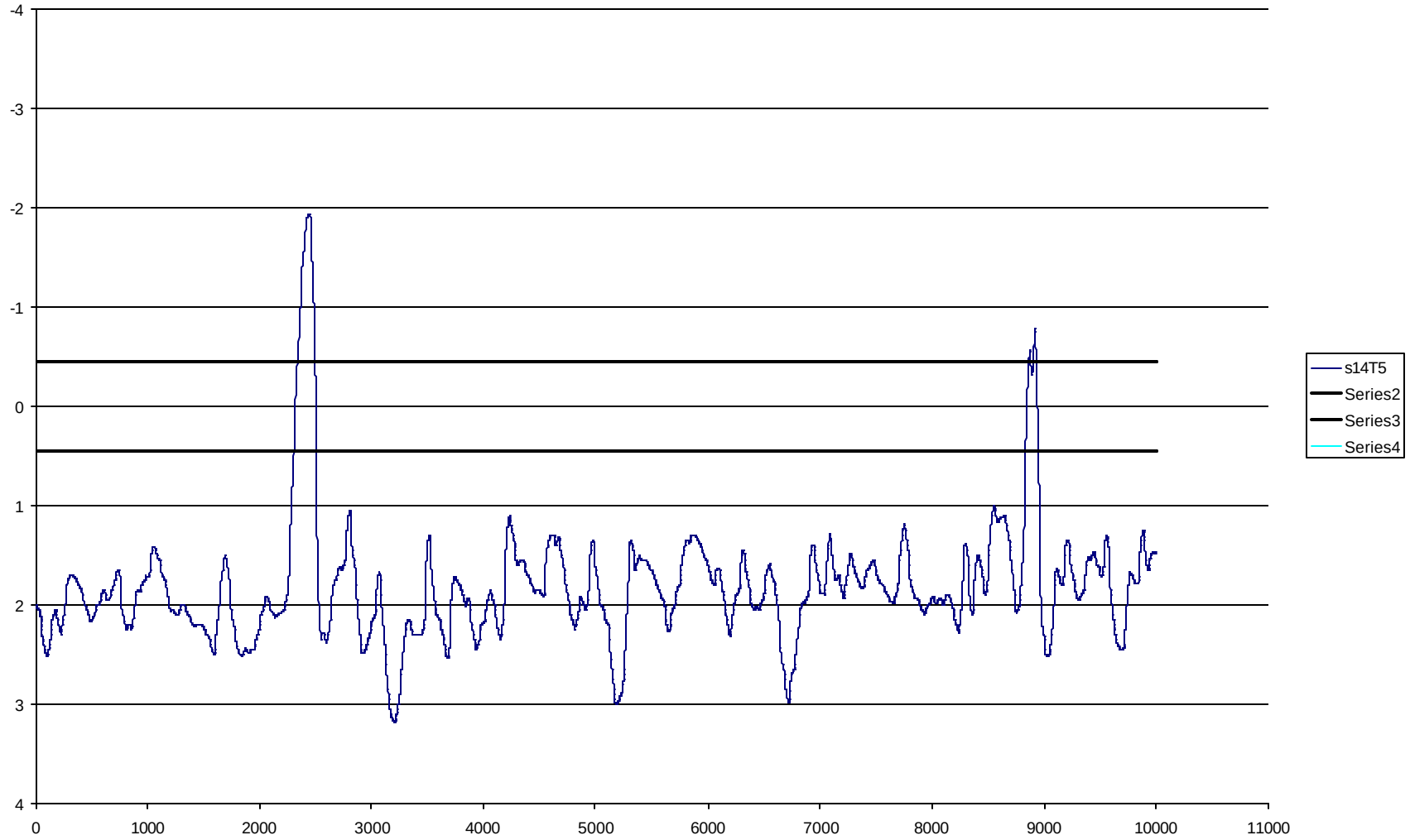

Figure 11: Example of trial in which there are two possible overtaking events at 2,400 meters and 8,800 meters. [Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition T5. Also appears as Figure A84 in Appendix A.]

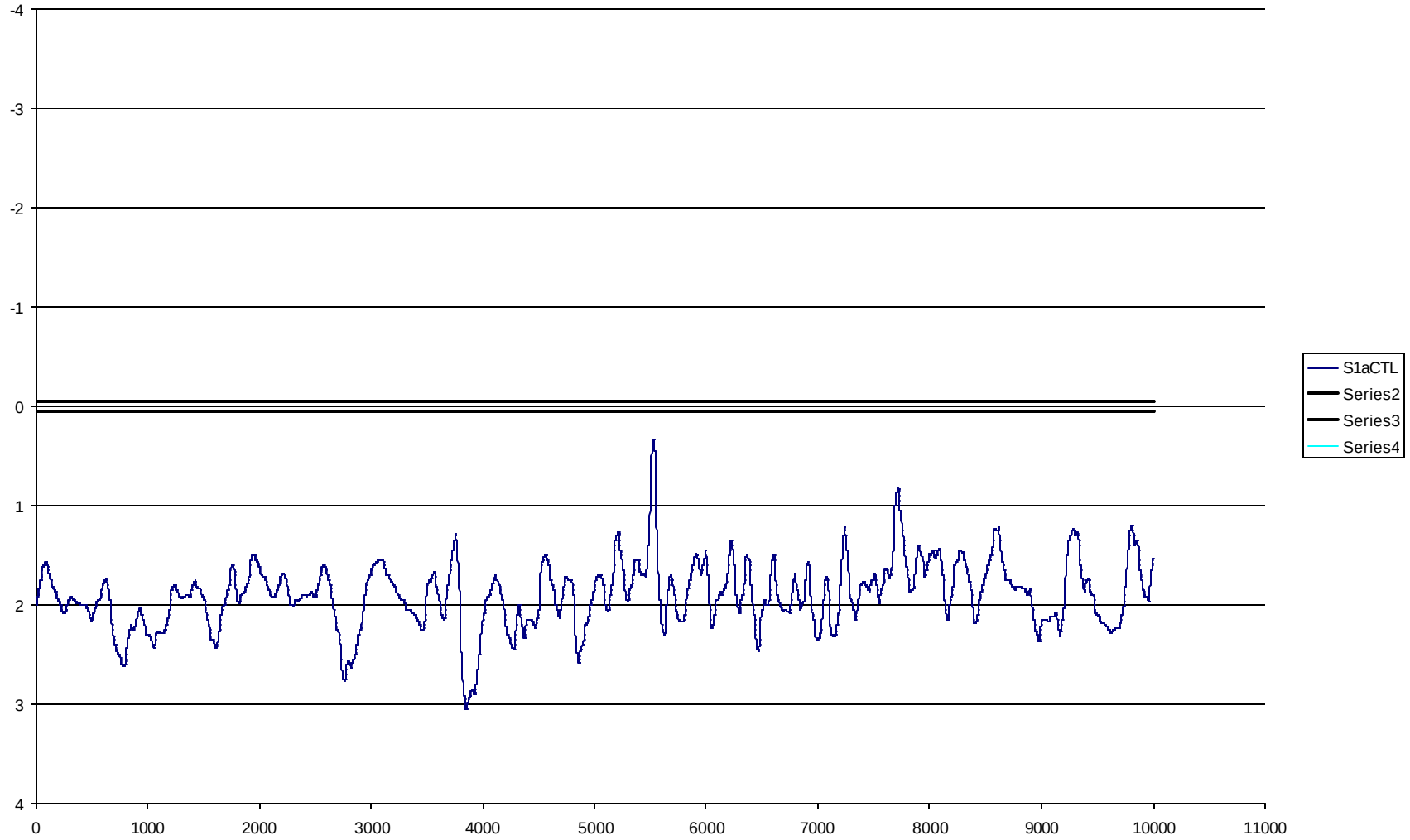

Figure 12: Example of trial with possible "looks" at 5,500 meters and 7,800 meters. [Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition CTL. Also appears as Figure A1 in Appendix A.]

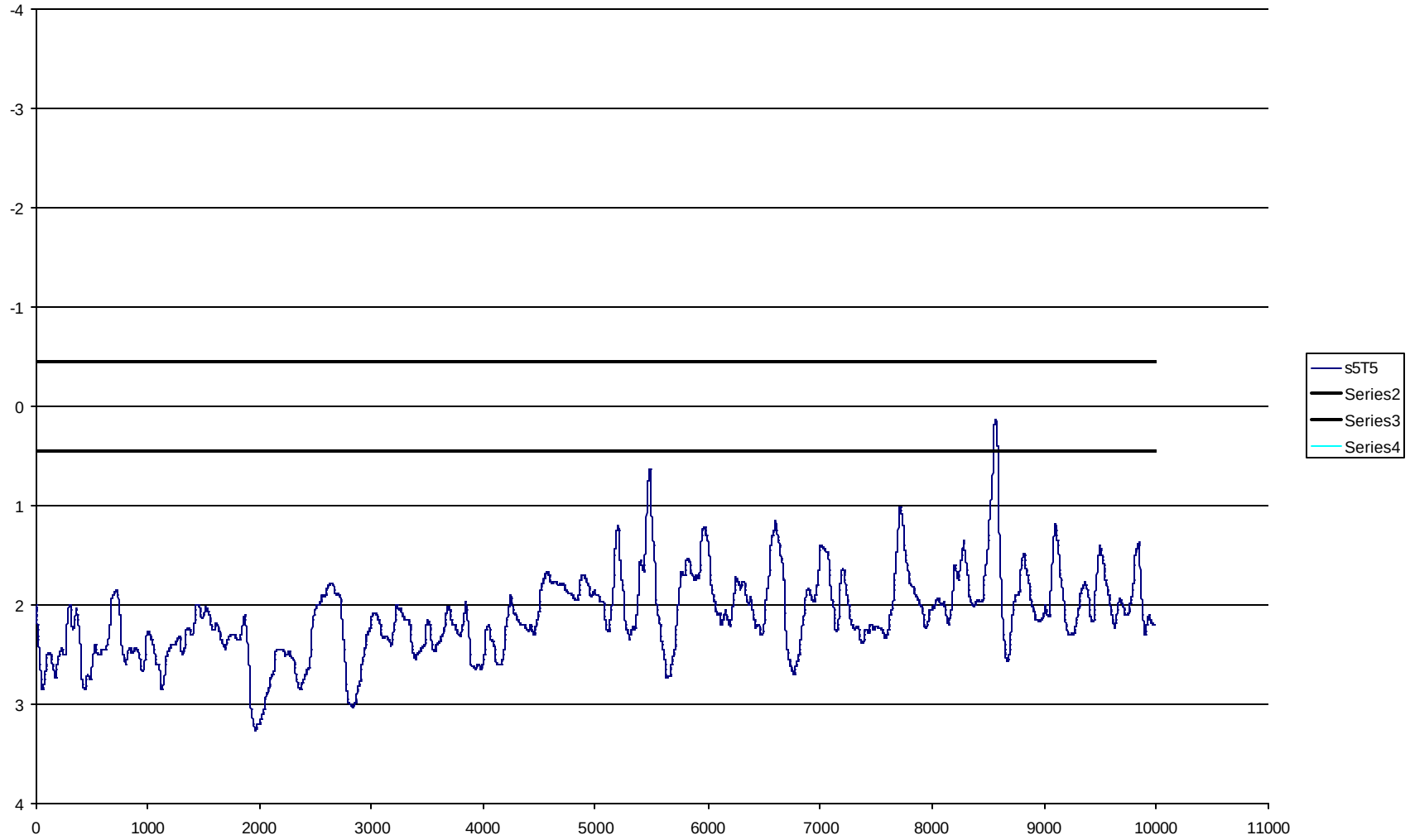

Figure 13: Example in which vehicle just crosses into central buffer area at 8,600 meters. [Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition T5. Also appears as Figure A30 in Appendix A]

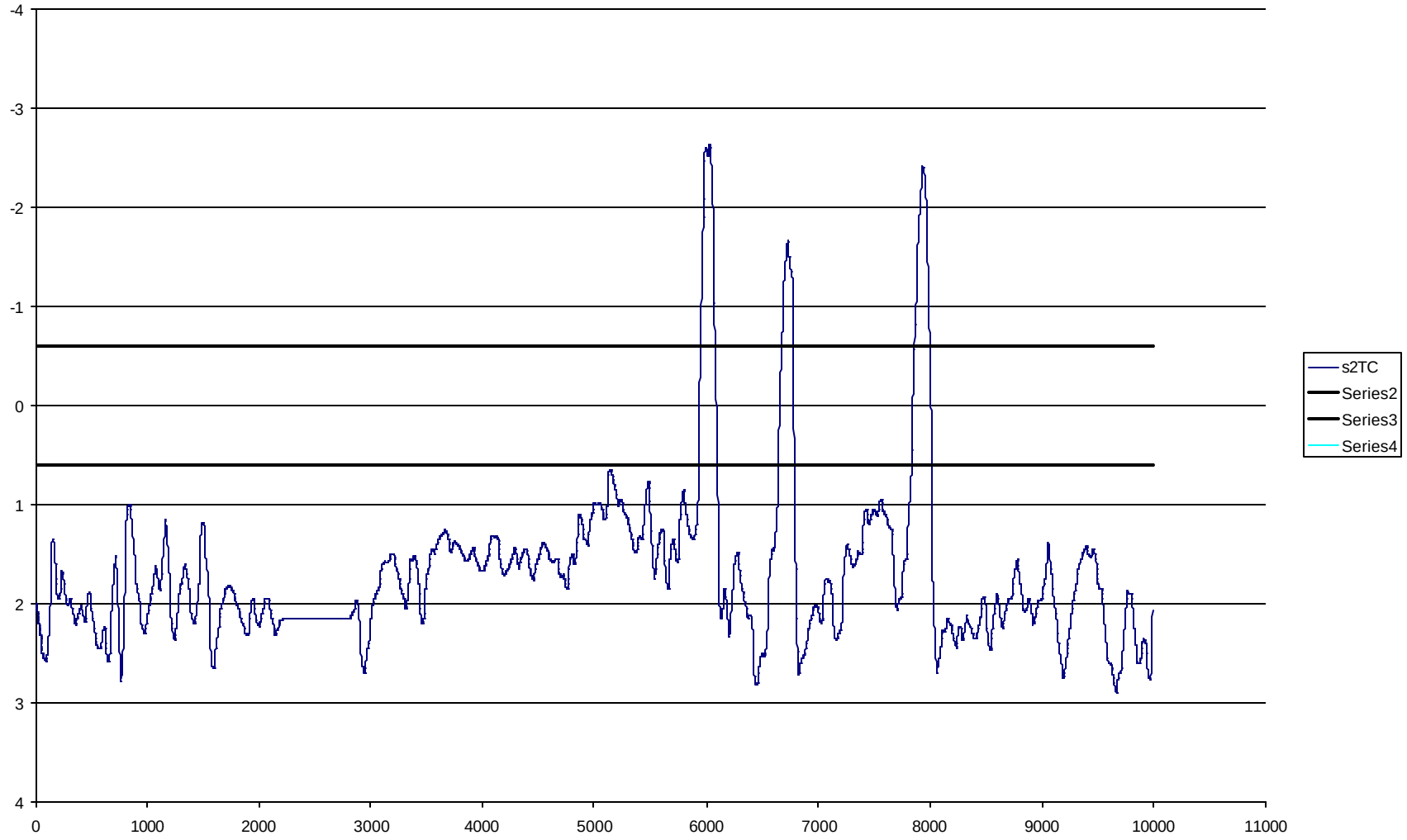

Figure 14: Example of "anticipatory" behavior between 5,200 and 6,000 meters, before possible overtaking events [Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition TC. Also appears as Figure A10 in Appendix A.]

First, Figure 10 illustrates a very commonly found "uneventful" Test Trial (Condition T5 in this case), in which the participant (S17) essentially drives a pathway, within the lane, and shows no sign of attempting to pass the vehicles in-lane ahead.

Second, Figure 11 shows a trial in which the participant (S14, in this particular case) makes two attempts to overtake a vehicle in-lane ahead when he or she is 2,400 meters and 8,800 meters from the start of the trial, while drives under Condition T5.

Third, Figure 12 shows an example of a trial in which, the participant (S1 in this case) clearly moves towards the centerline, and away from his or her normal pathway, in lane in order to "look" and see whether it may be possible to overtake. In this example, the participant was driving under Condition CTL.

Fourth, Figure 13 presents—after a "look" about 5,500 meters from the start of the trial—an example of a trial in which the participant (S5, this time) barely moves the simulator vehicle into the central buffer area, just crossing the left lane marker. This occurs 8,600 meters after the start of the trial and is probably an aborted attempt to overtake the vehicle in lane ahead. In this example, the participant was driving under Condition T5.

Fifth, Figure 14 shows an example of "anticipatory" behavior—i.e., in which the participant drove near the centerline and away from his or her normal pathway for an extended distance. In Figure 14, the participant (S2 driving under Condition TC in this case) exhibits this behavior between 5,200 and 6,000 meters from the start of the trial.

The categories illustrated in these Figures were used in assessing the participant's driving behavior. Table 8 shows, for each participant, the Test Trials that were assigned to the "uneventful" category—which was illustrated in Figure 10. In these trials, none of the other behaviors illustrated in Figures 11, 12, 13, and 14 were exhibited

Table 8: Centerline Treatment Conditions in which the participants experienced "uneventful" trials.

Participant	Condition CTL	Condition TB	Condition T3	Condition TC	Condition T4	Condition T5
S1	—	—	—	—	—	—
S2	—	—	—	—	X	—
S3	X	X	X	X	X	X
S4	—	—	—	—	—	—
S5	—	—	—	—	—	—
S6	—	X	X	X	X	X
S7	—	—	—	—	—	
S8	—	—	—	—	—	—
S9	X	—	X	—	—	—
S10	—	—	—	—	X	X
S11	X	—	X	—	—	—
S12	X	X	X	X	X	X
S13	—	X	—	—	—	—
S14	—	—	—	—	X	X
S15	X	X	—	—	X	X
S16	X	X	X	N/A	X	X
S17	X	X	—	—	—	—
S18	—	—	—	—	—	N/A
Total	7	7	6	3	8	6

The behaviors illustrated in Figures 11, 12, 13, and 14 are not mutually exclusive. The results of categorizing the behaviors illustrated by these figures are shown in the two parts of Table 9. It should be noted that the "aborted attempts to overtake" category illustrated in Figure 12, has been combined with the "attempts to overtake category" illustrated in Figure 11. This means that in Table 9, 14 instances of "aborted attempts to overtake" (six in Condition TC, five in Condition T4, and three in Condition T5) have been added to the more inclusive "attempts to overtake" category illustrated in Figure 11.

Table 9: Categorization of driving behaviors found when participants drove with:
(a) three Centerline Treatment conditions in which the centerline marked the lanes.

	Condition CTL Over-taking attempts	Condition CTL Possible "looks"	Condition CTL "Anticipa-tory" behavior	Condition TB Over-taking attempts	Condition TB Possible "looks"	Condition TB "Anticipa-tory" behavior	Condition T3 Over-taking attempts	Condition T3 Possible "looks"	Condition T3 "Anticipa-tory" behavior
S1	—	2	—	—	1	—	—	3	—
S2	1	2	—	1	—	—	1	2	—
S3	—	—	—	—	—	—	—	—	—
S4	5	4	—	3	1	—	3	—	—
S5	6	2	—	4	4	—	4	5	—
S6	—	1	—	—	—	—	—	—	—
S7	2	1	—	1	4	1	1	—	—
S8	—	2	—	—	3	—	—	—	—
S9	—	—	—	2	—	3	—	—	1
S10	—	2	—	—	1	1	—	1	1
S11	—	—	—	—	1	—	—	—	—
S12	—	—	—	—	—	—	—	—	—
S13	—	5	—	—	—	—	—	5	—
S14	3	—	—	3	—	—	2	—	—
S15	—	—	—	—	—	—	—	1	—
S16	—	—	—	—	—	—	—	—	—
S17	—	—	—	—	—	—	—	1	—
S18	—	6	—	—	1	—	—	3	—
Total	17	27	—	14	16	5	11	21	2

(b) Three Centerline Treatment conditions in which there was a central buffer area.

	Condition TC Over-taking attempts	Condition TC Possible "looks"	Condition TC "Anticipa-tory" behavior	Condition T4 Over-taking attempts	Condition T4 Possible "looks"	Condition T4 "Anticipa-tory" behavior	Condition T5 Over-taking attempts	Condition T5 Possible "looks"	Condition T5 "Anticipa-tory" behavior
S1	—	2	1	—	2	—	—	5	1
S2	3	—	1	—	—	—	4	—	3
S3	—	—	—	—	—	—	—	—	—
S4	8	—	—	1	—	—	3	—	—
S5	3	—	1	—	—	—	1	1	—
S6	—	—	—	—	2	—	—	2	—
S7	2	—	1	2	1	—	3	1	—
S8	1	—	2	3	—	—	1	2	—
S9	2	—	3	5	—	2	1	—	1
S10	1	—	1	—	—	—	1	1	—
S11	—	3	—	—	2	—	—	—	—
S12	—	—	—	—	—	—	—	—	—
S13	3	5	—	2	6	—	1	3	—
S14	2	—	1	—	—	—	2	—	—
S15	1	—	2	—	—	—	—	—	—
S16	X	X	X	—	—	—	—	—	—
S17	—	1	—	—	1	—	—	—	—
S18	—	4	—	—	4	—	X	X	X
Total	26	15	13	13	18	2	17	15	5

CHAPTER 4: DISCUSSION

Findings

Ekern's (1998) *Design Guidelines for Super Two Highways* called for improvements—such as flattening the slopes, and providing wide shoulders and adequate clear zones—that affect the roadway to the right side of the driver. In contrast, little was suggested for the left side, where drivers often experience speed differentials of 125 mph (200 km/h) between his or her vehicle and traffic in the opposing lane.

Our investigation of six experimental Centerline Treatments was undertaken to fill this void. The Treatment conditions tested were as follows.

- Condition CTL, the control condition, which has12-ft (3.6-meter) wide lanes and 4-inch (100-mm) wide dashes marking the centerline—and is the current US standard.
- Condition TB, which has increased 14-ft (4.2-meter) wide lanes, with 4-inch (100-mm) wide dashes marking the centerline.
- Condition T3, which has increased 14-ft (4.2-meter) wide lanes, and a longitudinal rumble strip as well as 4-inch (100-mm) wide dashes marking the centerline.
- Condition TC, which has two 12-ft (3.6-meter) wide lanes separated by a central buffer area that is 4 ft (1.2 meters) wide. The buffer area is bounded on both sides by 4-inch (100-mm) wide dashed lines. The centerline is not marked.
- Condition T4, which has two 12-ft (3.6-meter) wide lanes separated by a central buffer area that is 4 ft (1.2 meters) wide. The buffer area is bounded on both sides by longitudinal rumble strips. In the center of the central buffer area, there are 4-inch (100-mm) dashes marking the centerline.
- Condition T5, which has two 12-ft (3.6-meter) wide lanes separated by a central buffer area that is 4 ft (1.2 meters) wide. The buffer area is bounded on both sides by 8-inch (200-mm) wide dashes. The centerline is not marked.

Each of the 18 participants drove a 6.2-mile (10-km) bi-directional highway in six Test Trials. The order in which the centerline treatments were encountered was counterbalanced across participants—so that potential practice and fatigue effects were evenly distributed across the six treatments.

In each trial, the participant faced several different driving situations, including the following:

- Cruising with no traffic in the opposing lane.
- Cruising with traffic in the opposing lane.
- Following behavior, so that the driver had to adjust his or her speed to match that of the car in-lane ahead.
- Attempts to overtake the car in-lane ahead.

We examined whether mean lane position was affected by the first three of these driving situations. We discovered, as Figure 8 illustrates, that the participants drove further from the centerline (and the opposing lane) when they were cruising and there was traffic in the opposing lane, than they did for the other two driving situations when they were cruising and no opposing traffic was present. It is obviously better to drive further from the opposing lane when there is traffic in it, and it was encouraging to discover that the participants actually did this.

We also discovered, as Figure 8 also shows, that the participants drove further from the centerline when they were cruising and there was traffic in the opposing lane, than they did when they were involved in following behavior—i.e. when they were close enough to a vehicle in-lane ahead to have to respond to it. The way they drove when following was similar to the way they drove when cruising with no opposing traffic present. This suggests that, when following behavior occurred, the participants drove using the vehicle ahead as a point of reference, rather than using static road features as referents.

It is also worth noting that in this experiment the vehicles that were in-lane ahead were programmed to travel in the center of the lane and make no adjustment to their lane

position when encountering opposing traffic. In this respect, the simulated vehicles did not act in the same way as real world traffic. This should not be considered a design flaw—if the simulated vehicles in-lane ahead had reacted to the oncoming traffic, we would have been unable to discover that the participants used the vehicle ahead as a referent for maintaining lane position.

Figure 8 also provides information concerning the effect of the Centerline Treatments. The figure indicates that the participants were further away from the centerline when they drove with all five of the experimental Centerline Treatments than they were when they drove in the control condition (Condition CTL), which is the current US standard.

Figure 9 shows the relationship between Centerline Treatments and lane position relative to the edge of the left lane marker. The figure indicates that participants drove at approximately the same distance from the edge of the left lane marker for all four Centerline Treatment conditions in which there were two 12-ft (3.6-meter) wide lanes—i.e., the control Condition CTL, and Conditions TC, T4, and T5, which were the Centerline Treatment conditions in which the two 12-ft (3.6-meter) wide lanes were separated by a 4-ft (1.2-meter) wide central buffer area. It is also noteworthy that for all four of these Centerline Treatment conditions, the mean lane positions were between 1.7 meters and 1.85 meters for the driving situations involving "cruising when no opposing traffic was present" and "following" a vehicle in-lane ahead. Because "lane position" in this study was defined as *lane position in reference to the left edge of the simulator vehicle*, the 1.7 meters and 1.85 meter values indicate that, in these driving situations, participants kept the left side of the vehicle approximately in the center of the lane, for all four of these Centerline Treatments.

Further, for the remaining two Centerline Treatments—Conditions TB and T3, both of which had 14-ft (4.2-meter) wide lanes—the mean lane positions were between 1.95 meters and 2.1 meters, for the driving situations involving "cruising when no opposing traffic was present" and "following" a vehicle in-lane ahead. These values indicate that, in these driving situations, the participants kept the left side of the vehicle approximately

in the center of the lane for these two Centerline Treatments as well. The pairwise analysis of Figures A1 through A106 also indicated that the pathway of the vehicle was significantly further from the left lane marker for these two conditions.

Inspection of Figures A1 through A106, shows another important result: the participants did not straddle the centerline in Treatment Conditions CTL, TB and T3, nor did they drive in the central buffer area and use it as an extra lane in Treatment Conditions TC, T3, and T5.

Tables 8 and 9 presented information about the relationship between various driving behaviors and the Centerline Treatments. Table 8 showed that there were fewer "uneventful" trials with Treatment Condition TC. Table 9 showed that there were 27 attempts to overtake for Condition TC; this was more than for any other condition, and twice as many as for Treatment Conditions TB, T3, and T4.

Finally, with regard to changes in width of the road, Figure 8 suggests that if 12-ft (3.6-meter) lanes with a 4-ft (1.2-meter) wide center buffer area are implemented, then drivers will select pathways in the lane that are further from the centerline than they will if 14-ft (4.2-meter) lanes are implemented. With regard to variations in the left lane markings, inspection of Figure 8 suggests that conventional 4-inch (100 mm) white dashed lines are as effective as longitudinal rumble strips, and that doubling the width of the dashes to 8-inch (200-mm) does not affect mean lane position.

Recommendations

In all Centerline Treatment conditions, the participants drove with the left side of the vehicle approximately in the center of the lane. And all five of the experimental Centerline Treatments resulted in the center of the lane being further away from the centerline than it is in the control condition. The combination of these two facts resulted in the participants driving further away from the centerline in the presence of the five experimental Centerline Treatments than they did in the control condition (Condition CTL). Therefore, if one of these five experimental Treatments were to be implemented

by Mn/DOT, it should result in drivers driving pathways in-lane that are further away from opposing lanes, making it less likely that they meet an oncoming vehicle.

If a choice is to be made between the five experimental centerline conditions on the basis of keeping drivers away from the centerline, then Figure 8 suggests that Conditions TC and T3 might be the most effective. If the ability to overtake is also used as a factor, then Table 9 suggests that Treatment Condition TC is likely to produce more overtaking attempts than the other four experimental Treatment Conditions—though it is debatable whether or not this is a beneficial attribute.

This report documents the effects of six Centerline Treatments on the driving performance of 18 participants. The results reported here and the recommendations made to use T3 and TC may be useful to Mn/DOT in upgrading its *Design Guidelines for Super Two Highways*. However, it must be remembered that the experiment was conducted with a driving simulator, and further testing of these two alternatives should be conducted on a closed track or actual highways.

REFERENCE

Ekern, D.S. (1998). *Design Guidelines for Super Two Highways*. Minnesota Department of Transportation, Engineering Services Division, Technical Memorandum Number 98-08-ES-01, issued May 18, 1998.

APPENDIX A

Lane Position for Each of the Six Centerline Treatments for Each of the 18 Participants

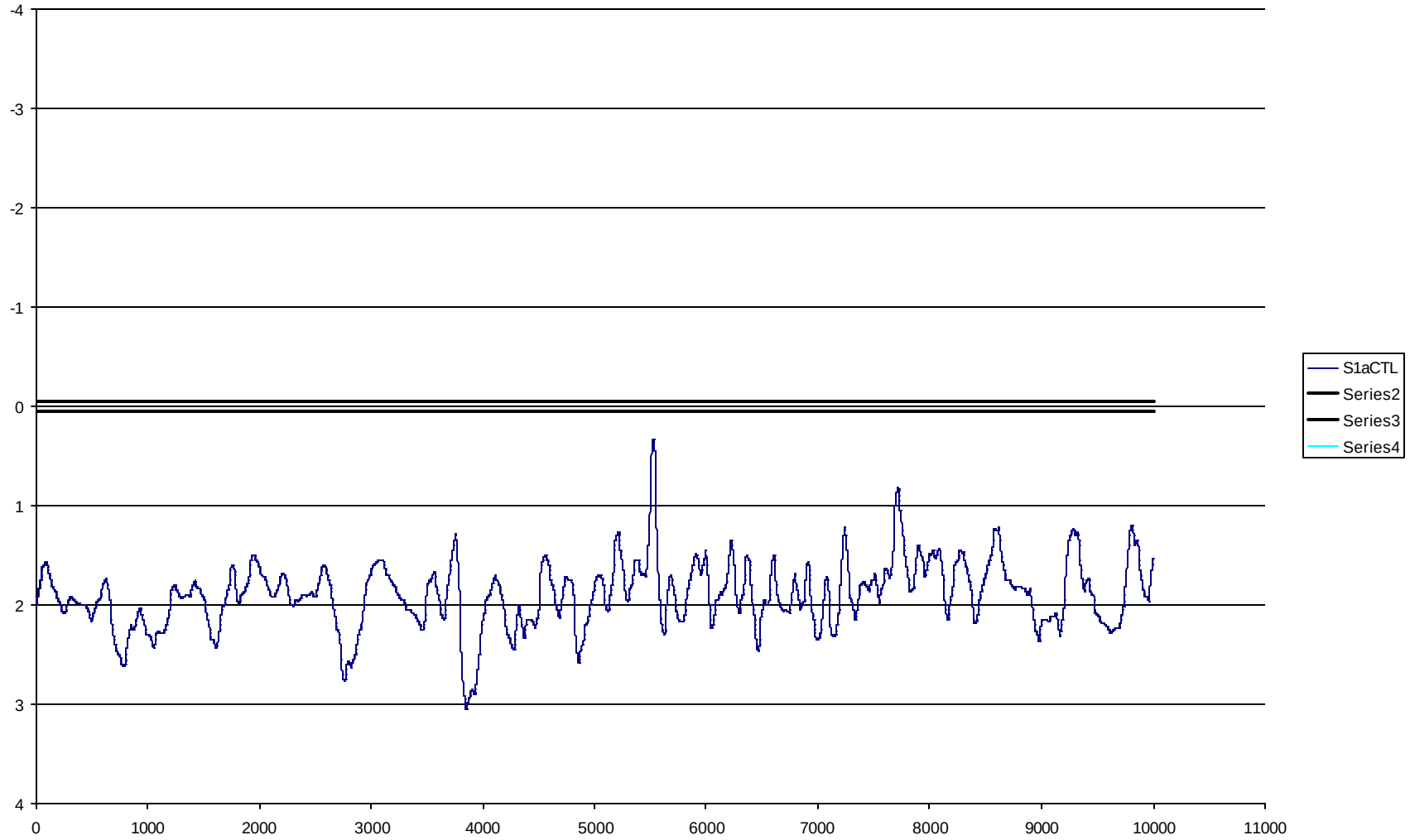

Figure A1: Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition CTL.

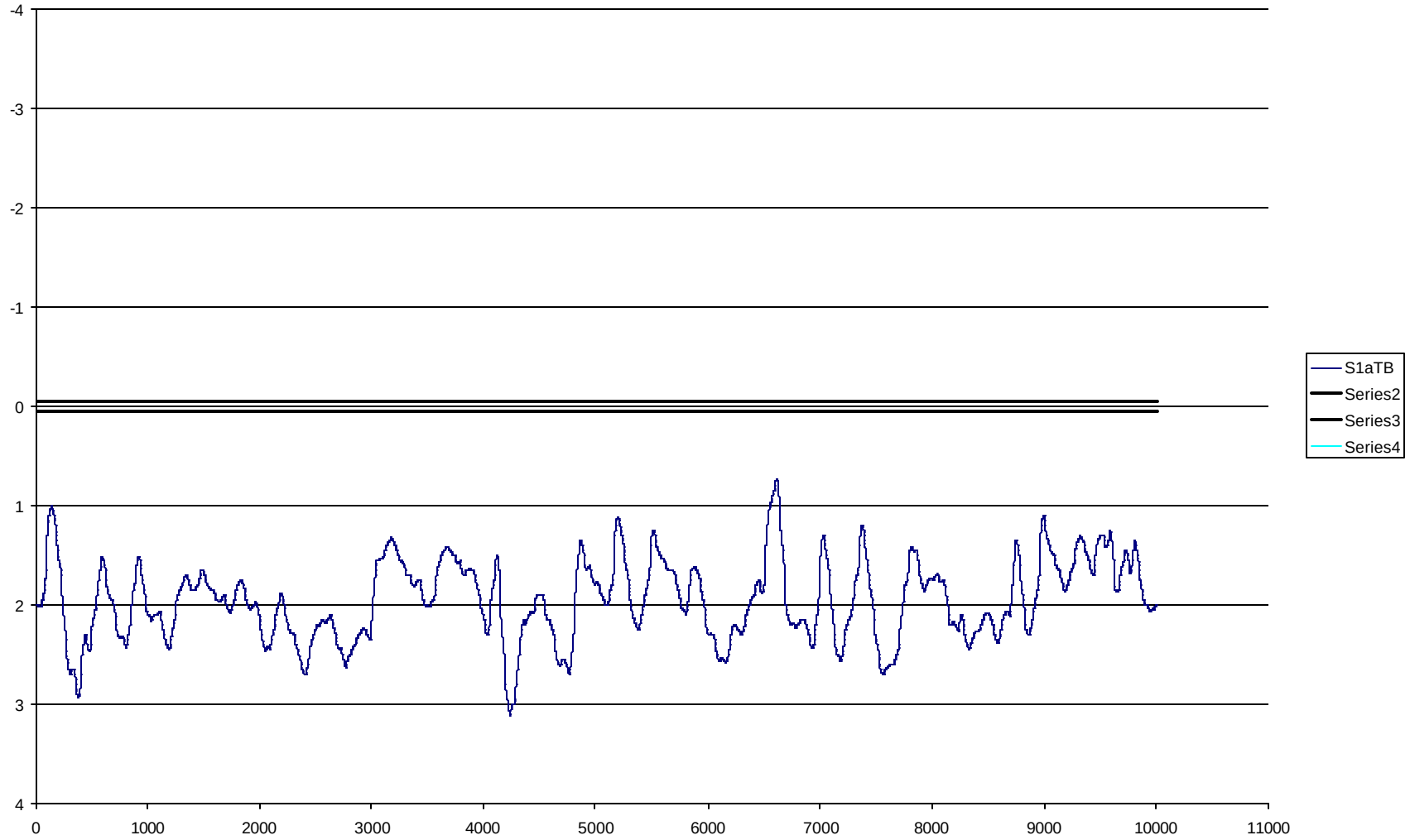

Figure A2: Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition TB.

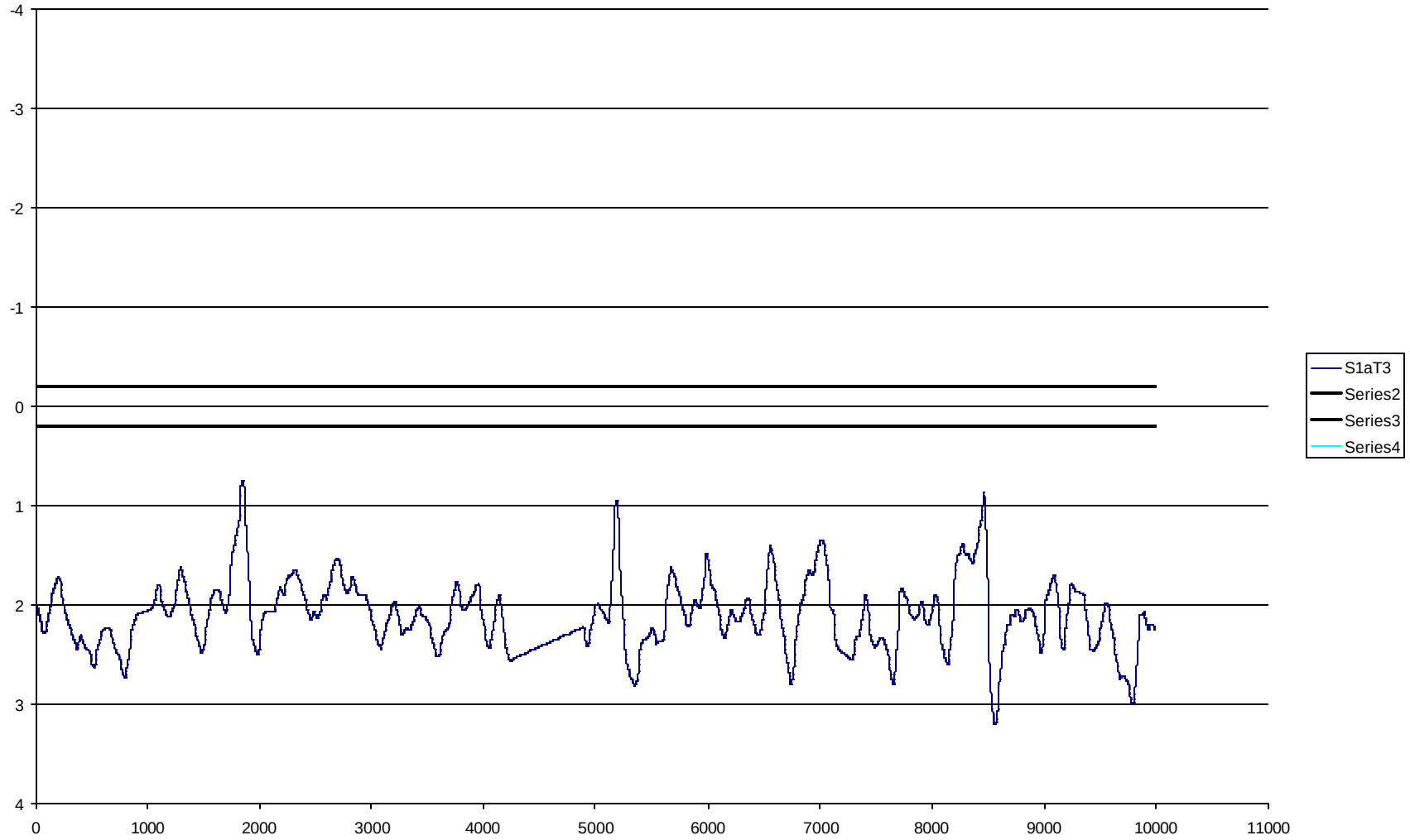

Figure A3: Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition T3.

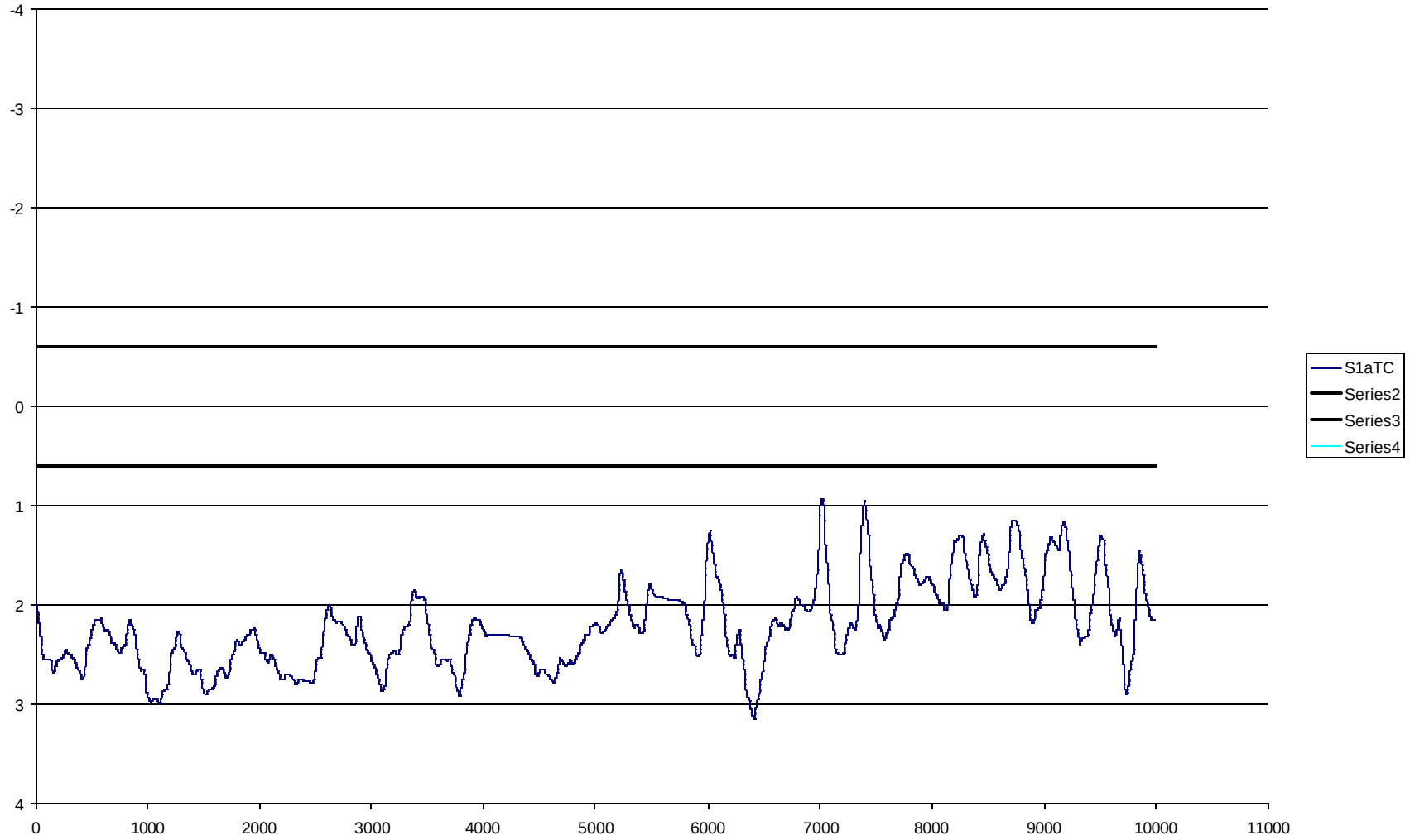

Figure A4: Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition TC.

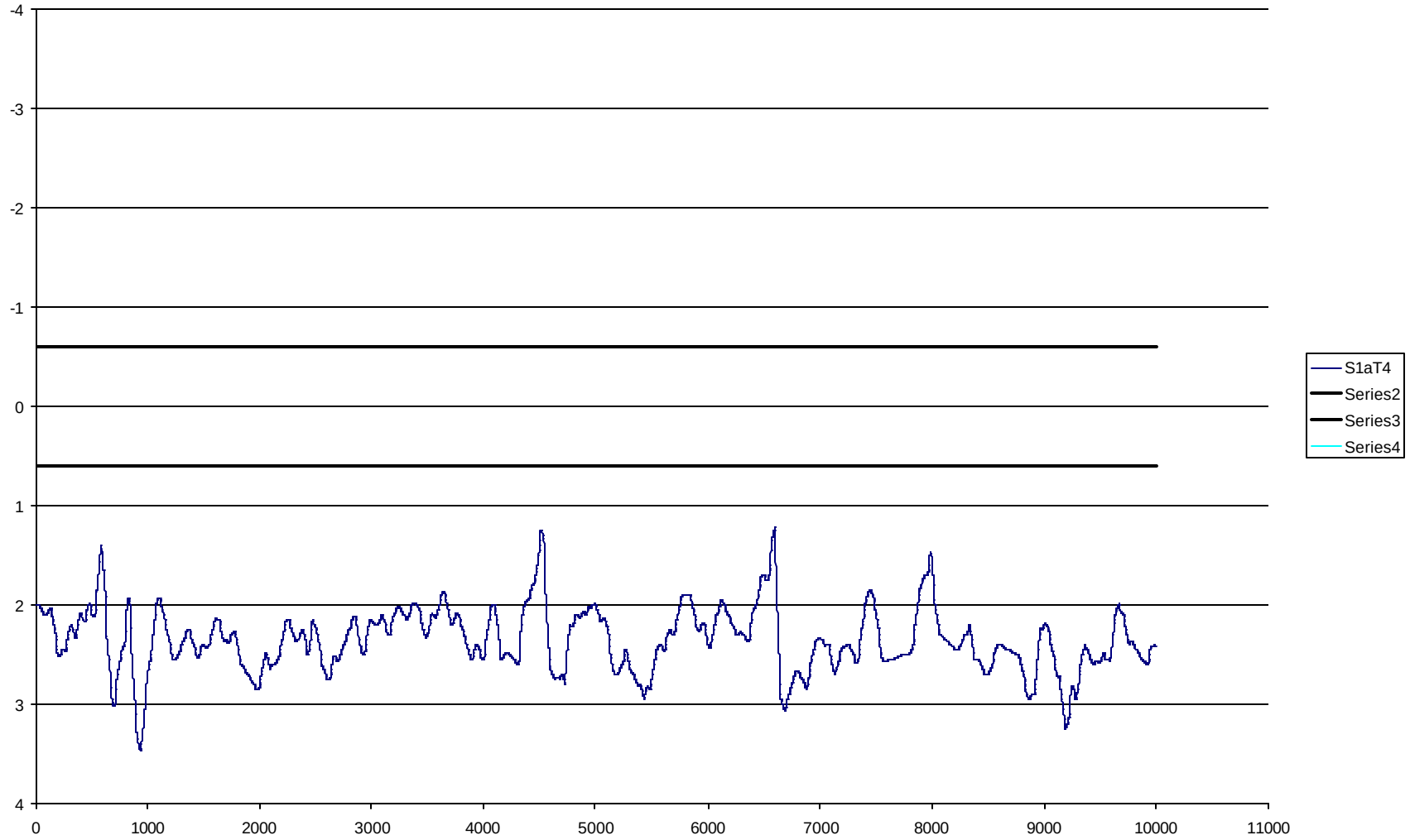

Figure A5: Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition T4.

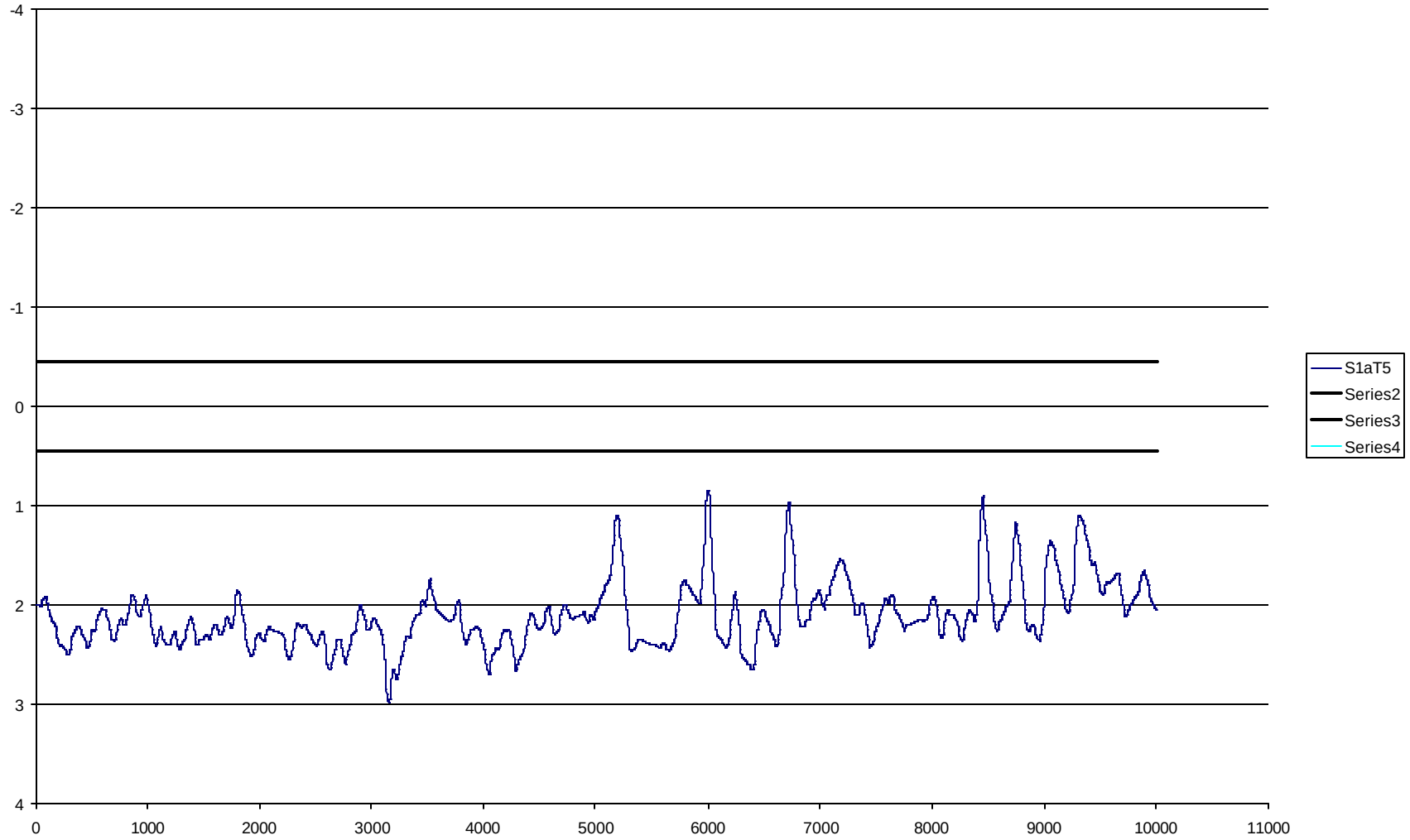

Figure A6: Lane position (in meters relative to center of road) for S1 driving for 10 km under Condition T5.

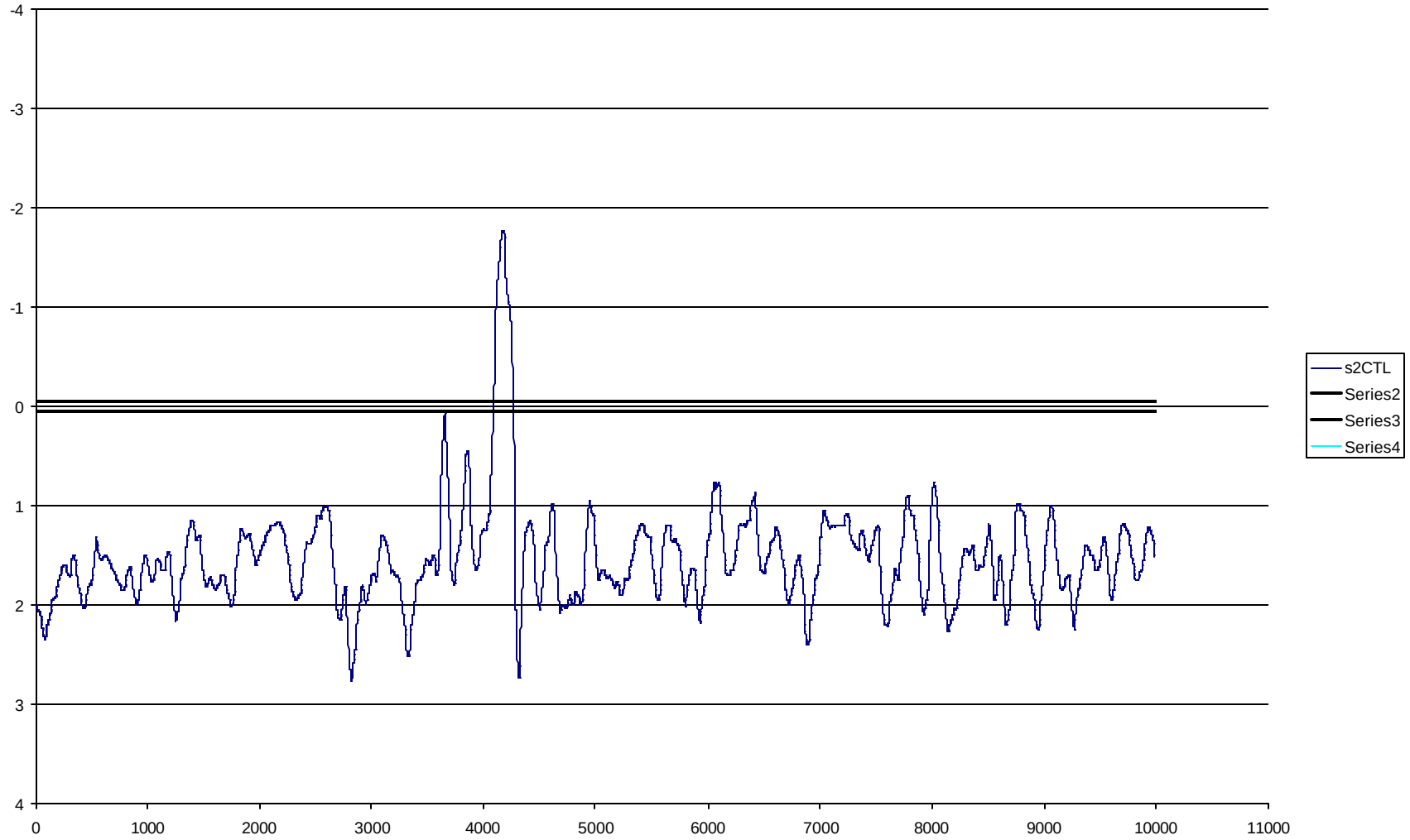

Figure A7: Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition CTL.

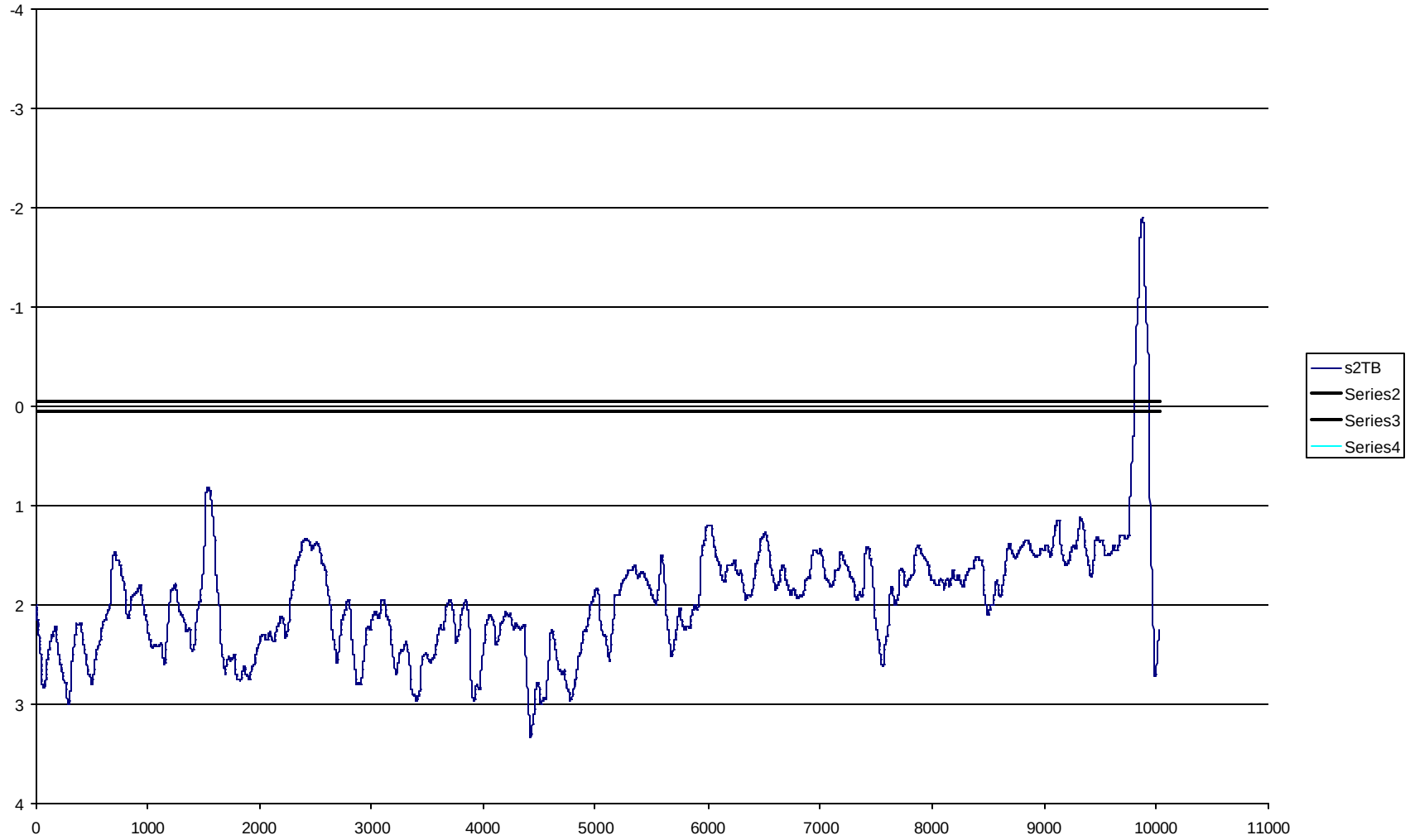

Figure A8: Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition TB.

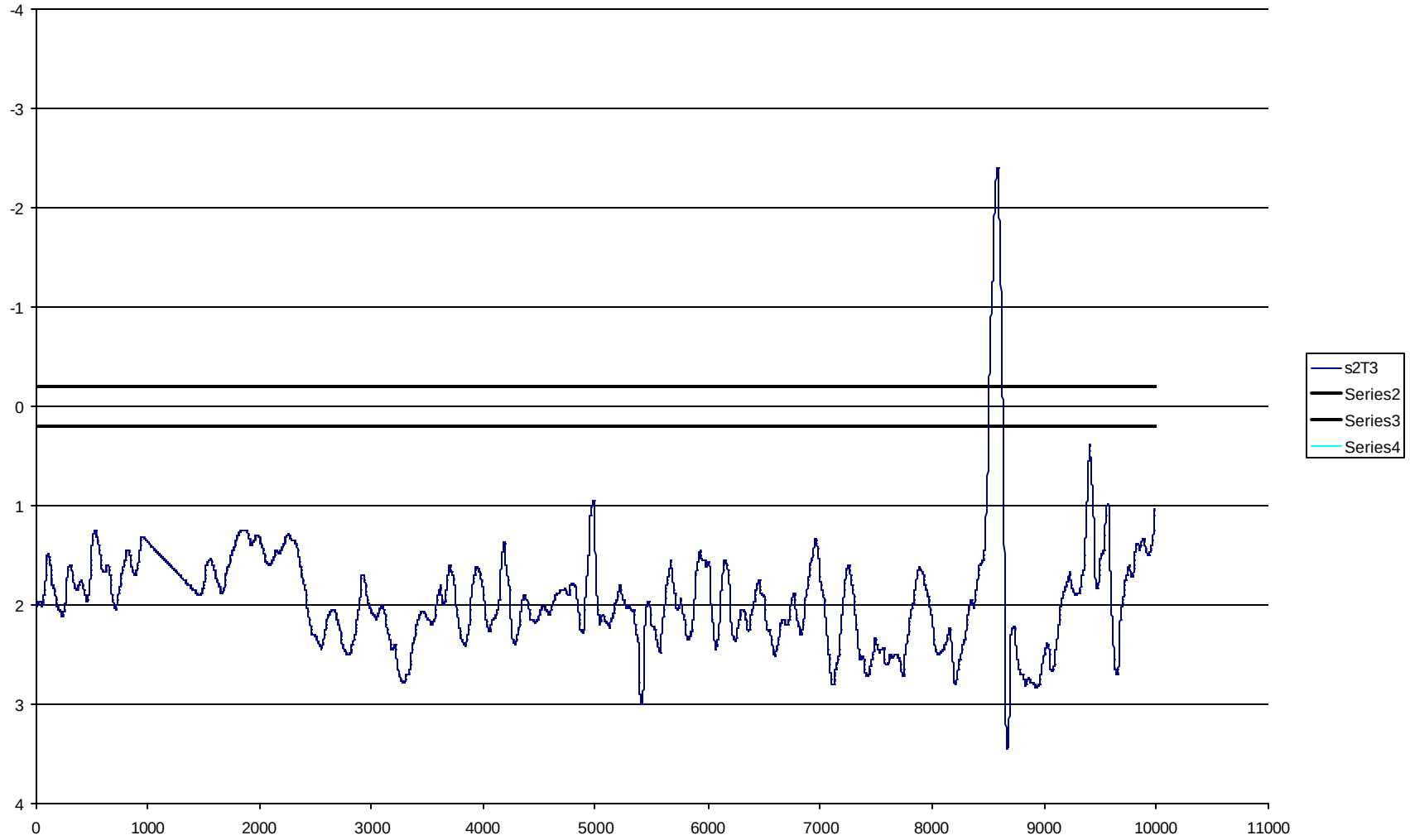

Figure A9: Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition T3.

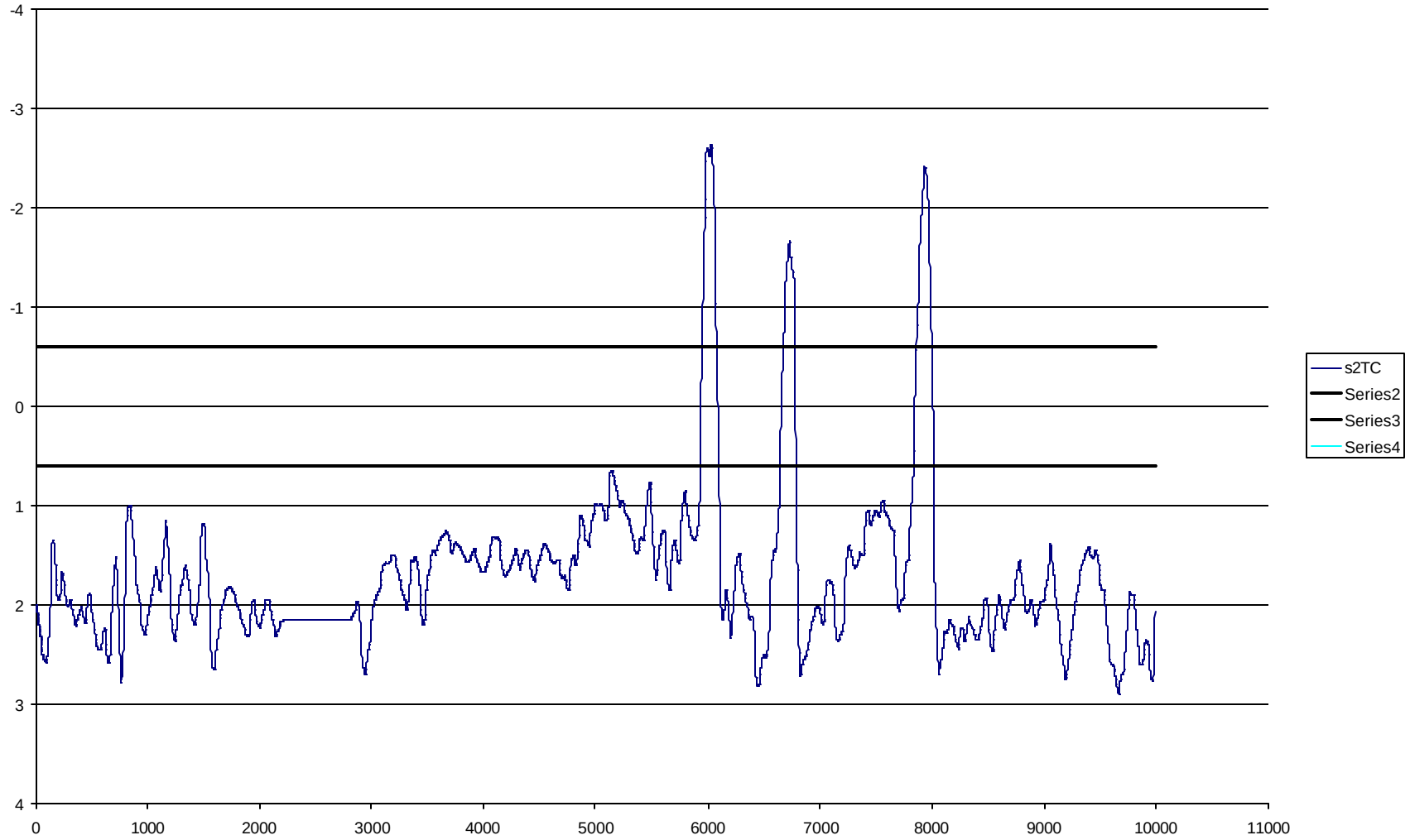

Figure A10: Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition TC.

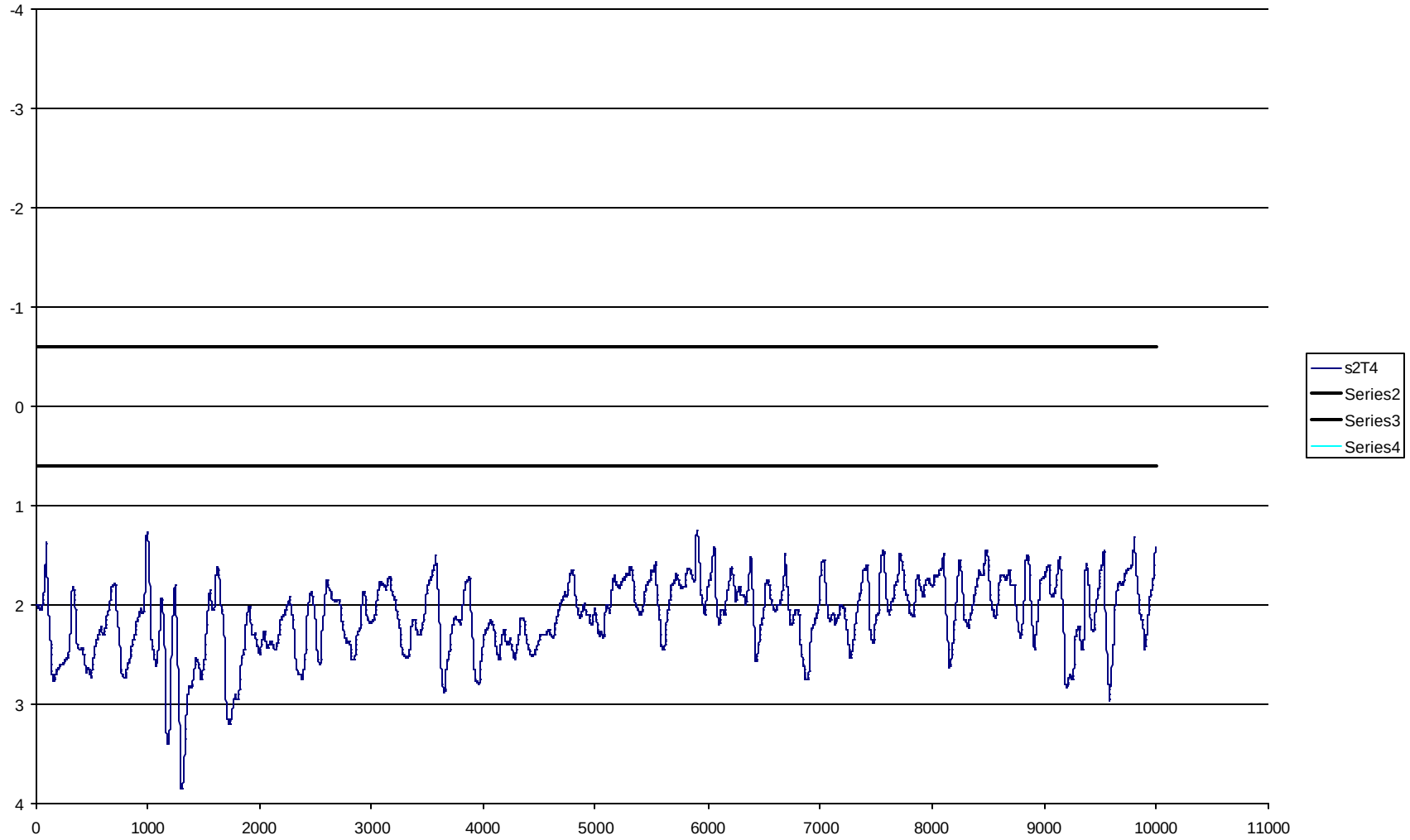

Figure A11: Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition T4.

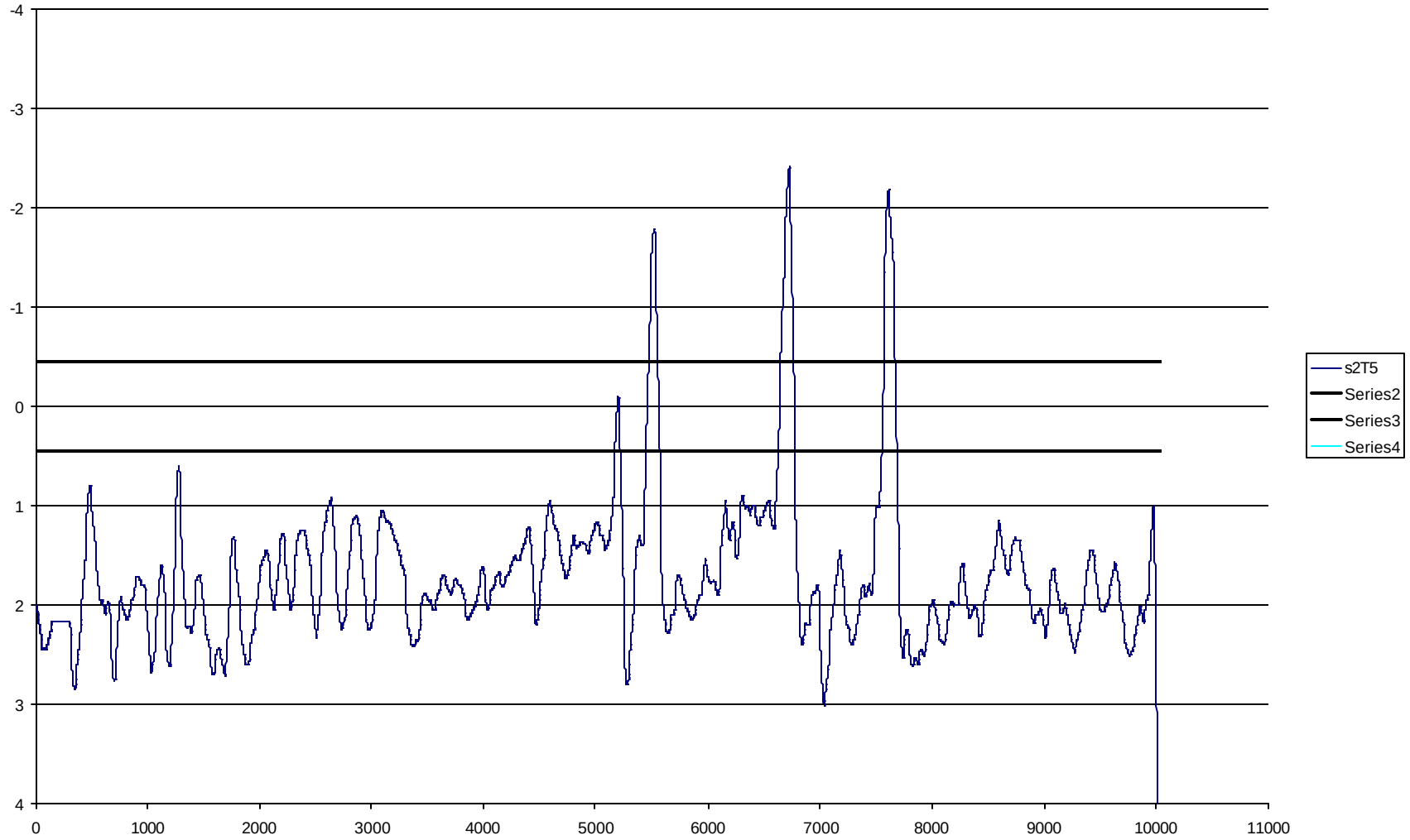

Figure A12: Lane position (in meters relative to center of road) for S2 driving for 10 km under Condition T5.

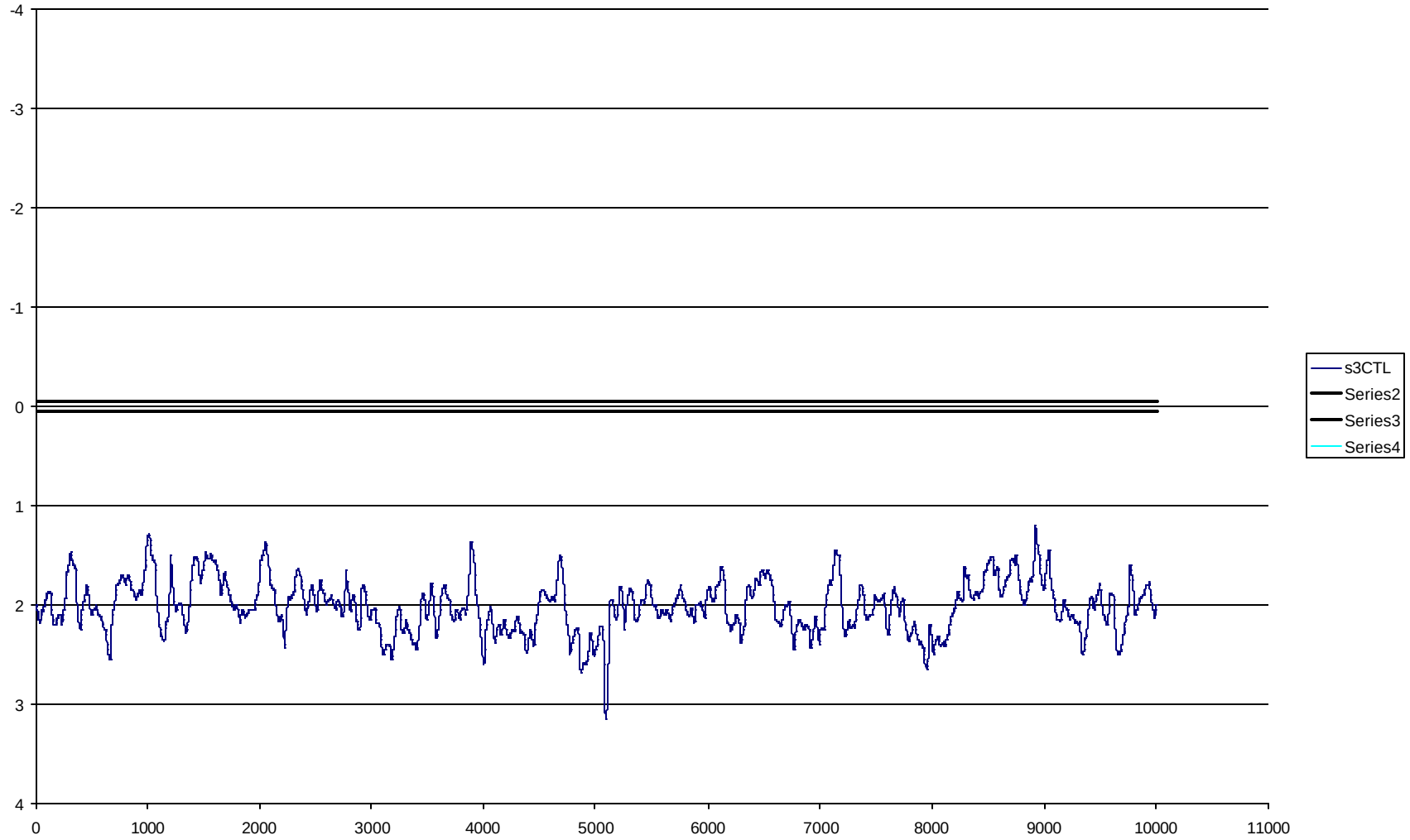

Figure A13: Lane position (in meters relative to center of road) for S3 driving for 10 km under Condition CTL.

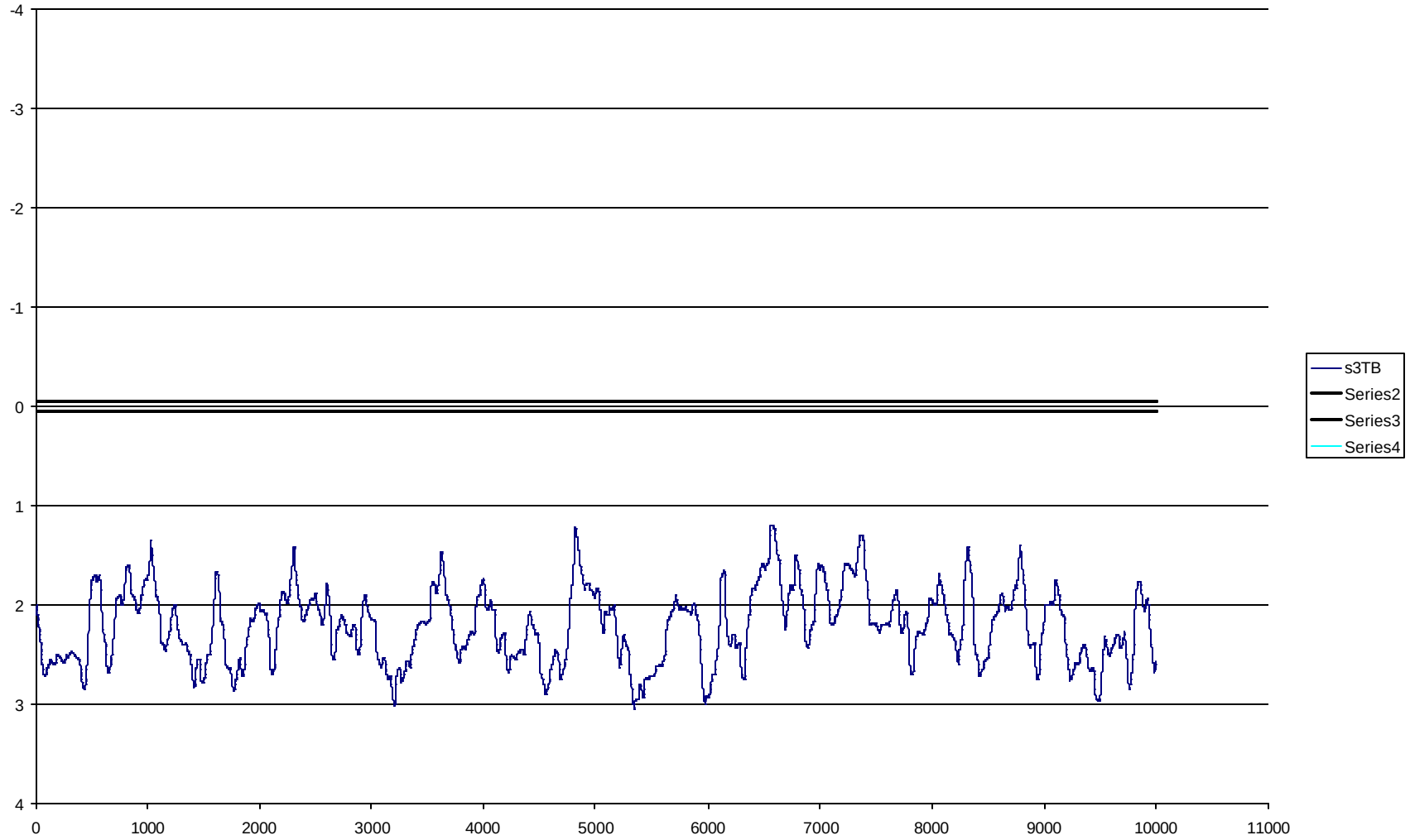

Figure A14: Lane position (in meters relative to center of road) for S3 driving for 10 km under Condition TB.

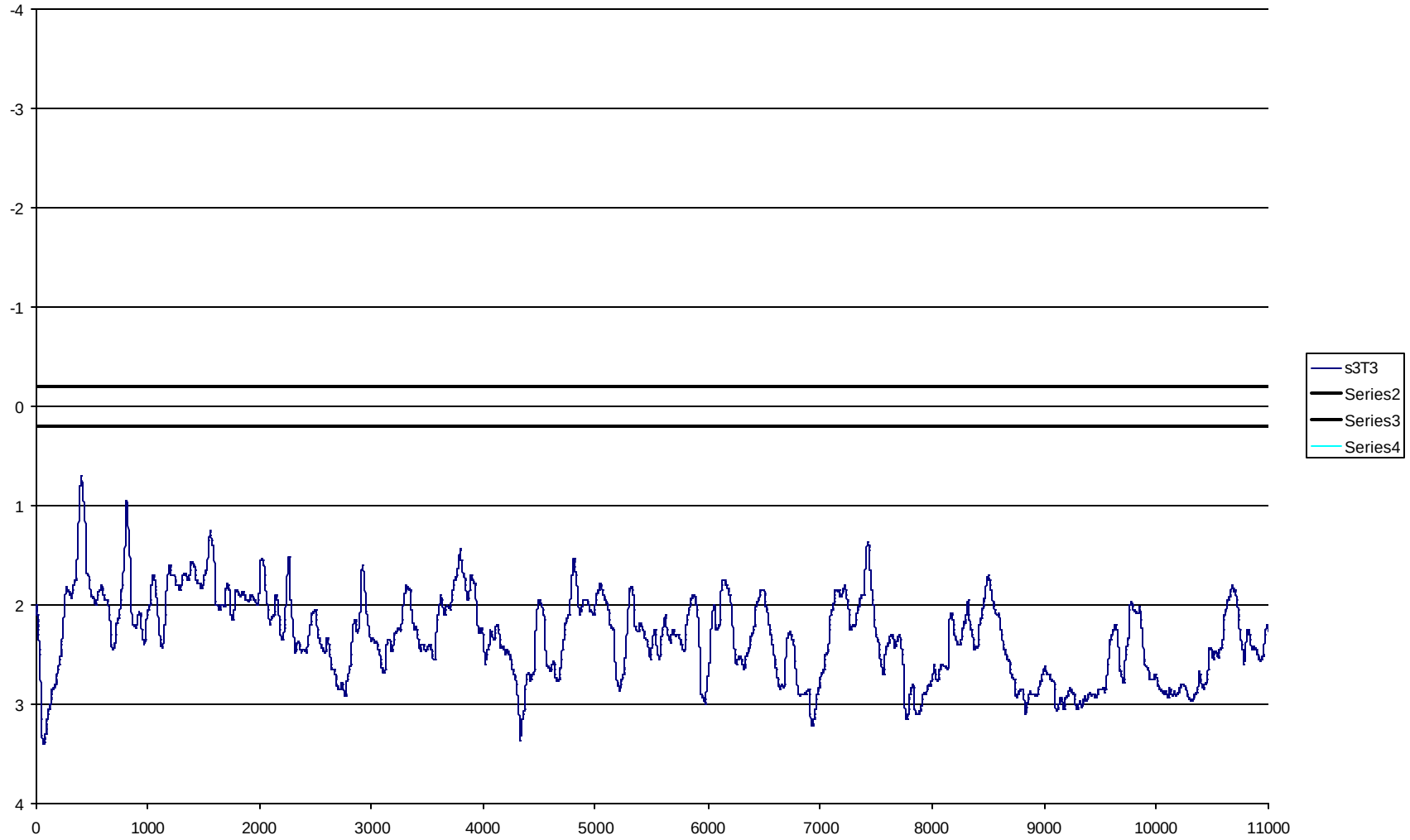

Figure A15: Lane position (in meters relative to center of road) for S3 driving for 10 km under Condition T3.

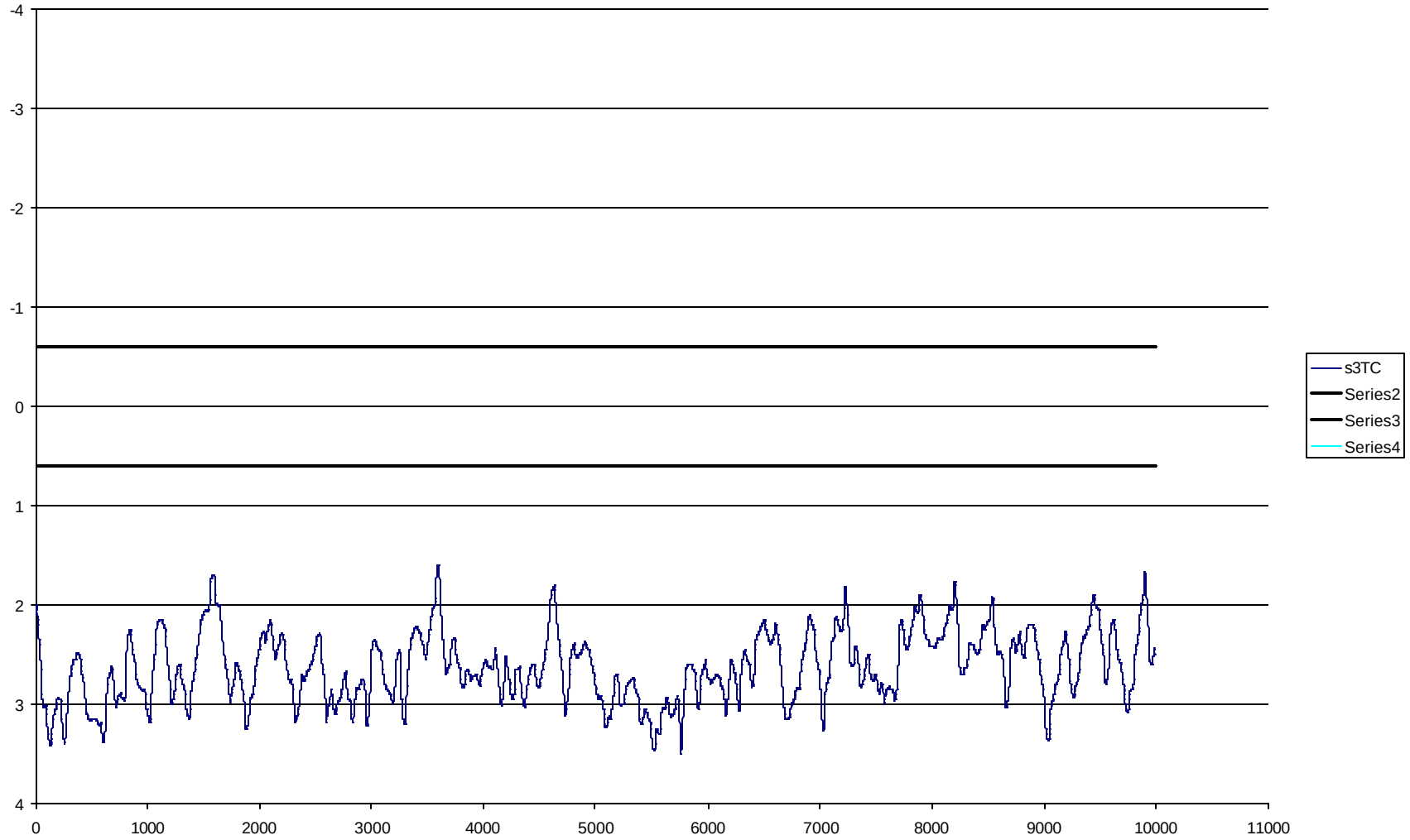

Figure A16: Lane position (in meters relative to center of road) for S3 driving for 10 km under Condition TC.

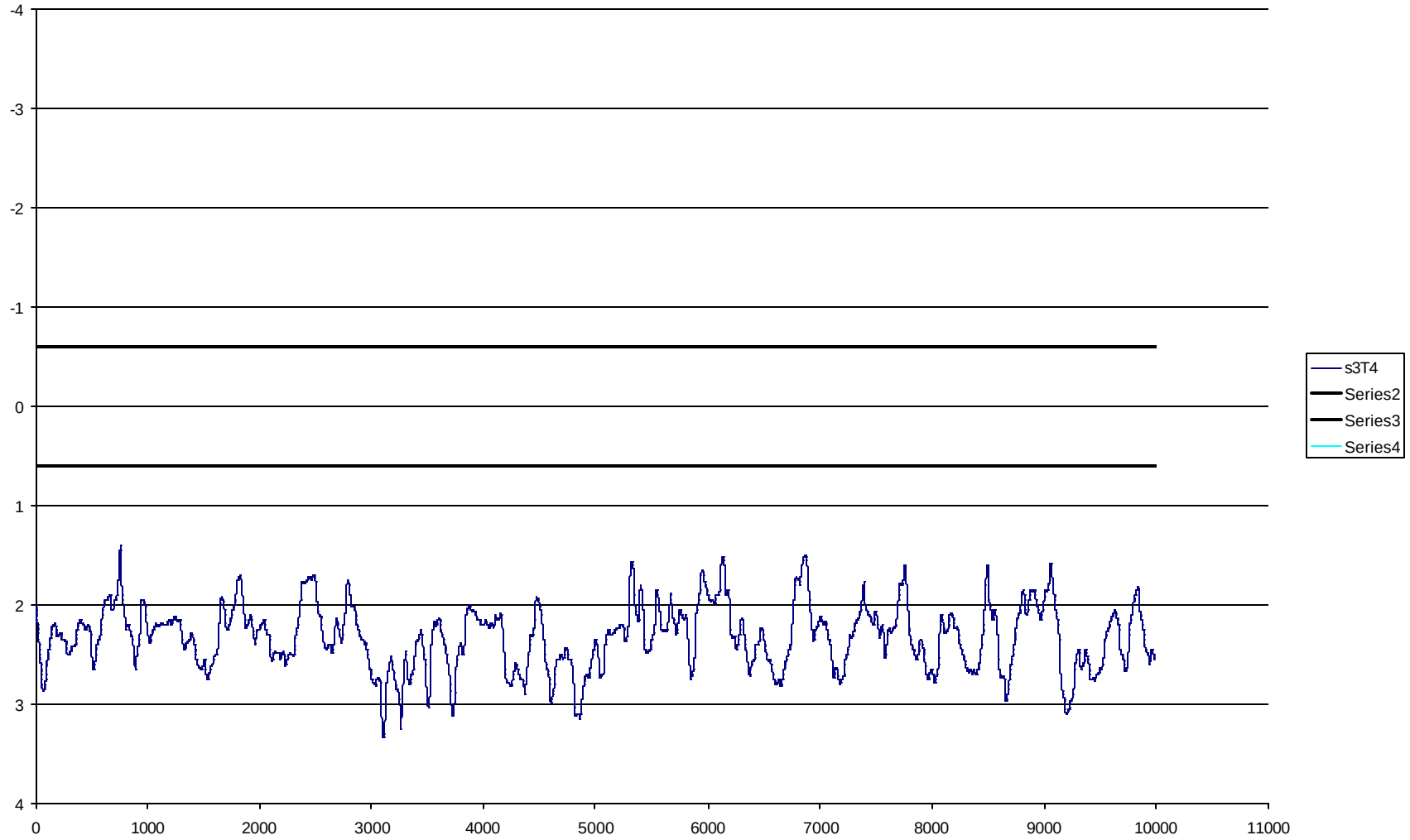

Figure A17: Lane position (in meters relative to center of road) for S3 driving for 10 km under Condition T4.

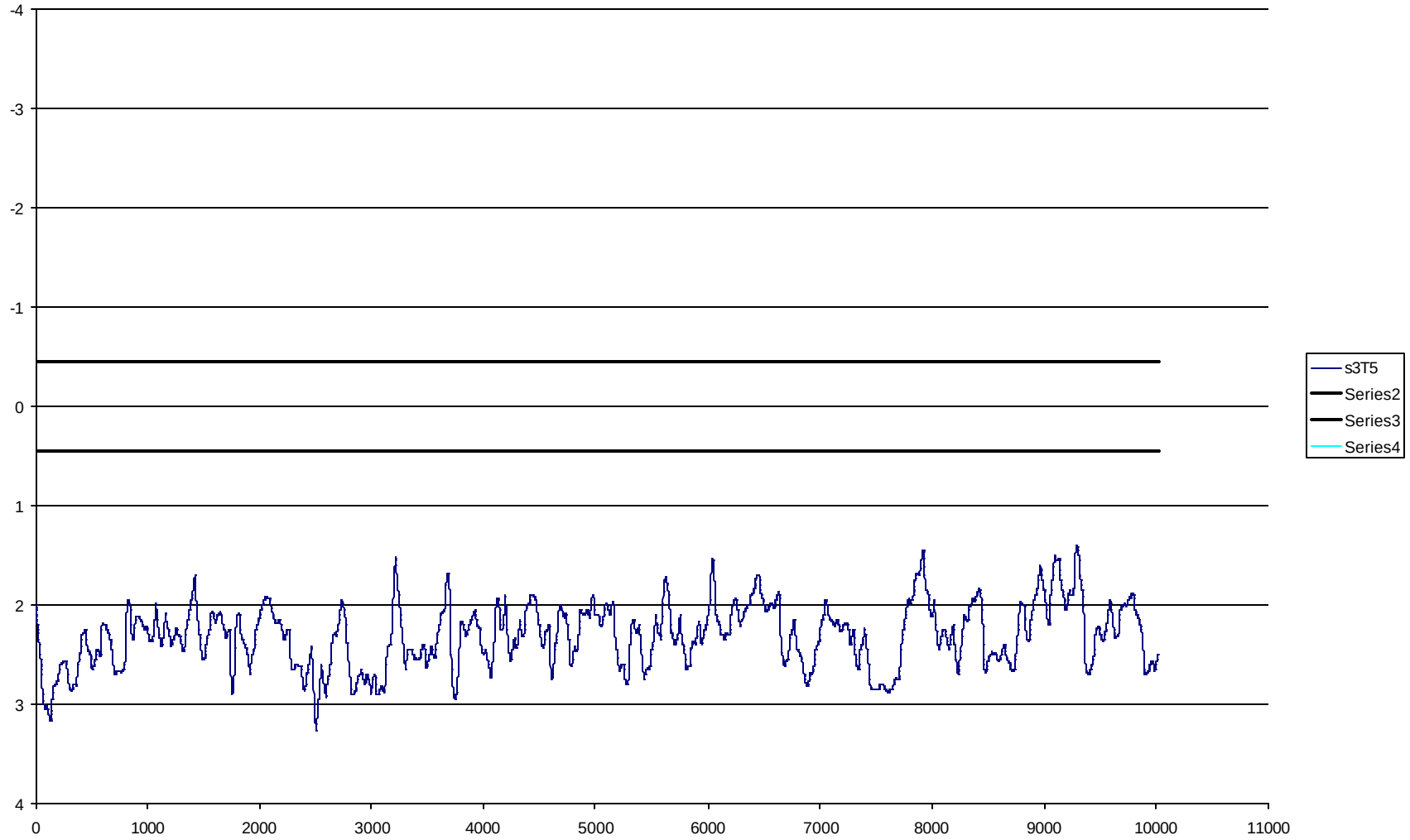

Figure A18: Lane position (in meters relative to center of road) for S3 driving for 10 km under Condition T5.

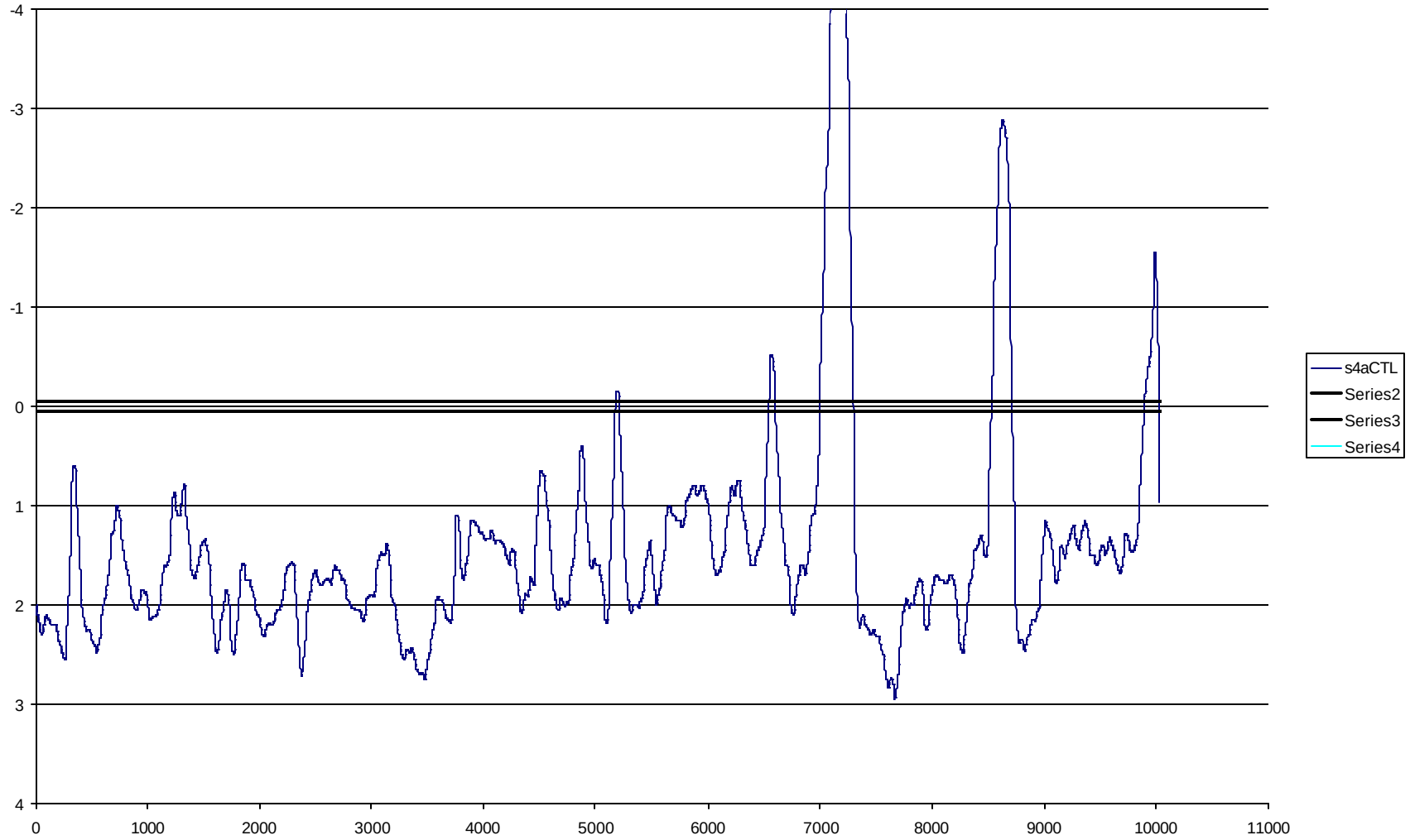

Figure A19: Lane position (in meters relative to center of road) for S4 driving for 10 km under Condition CTL.

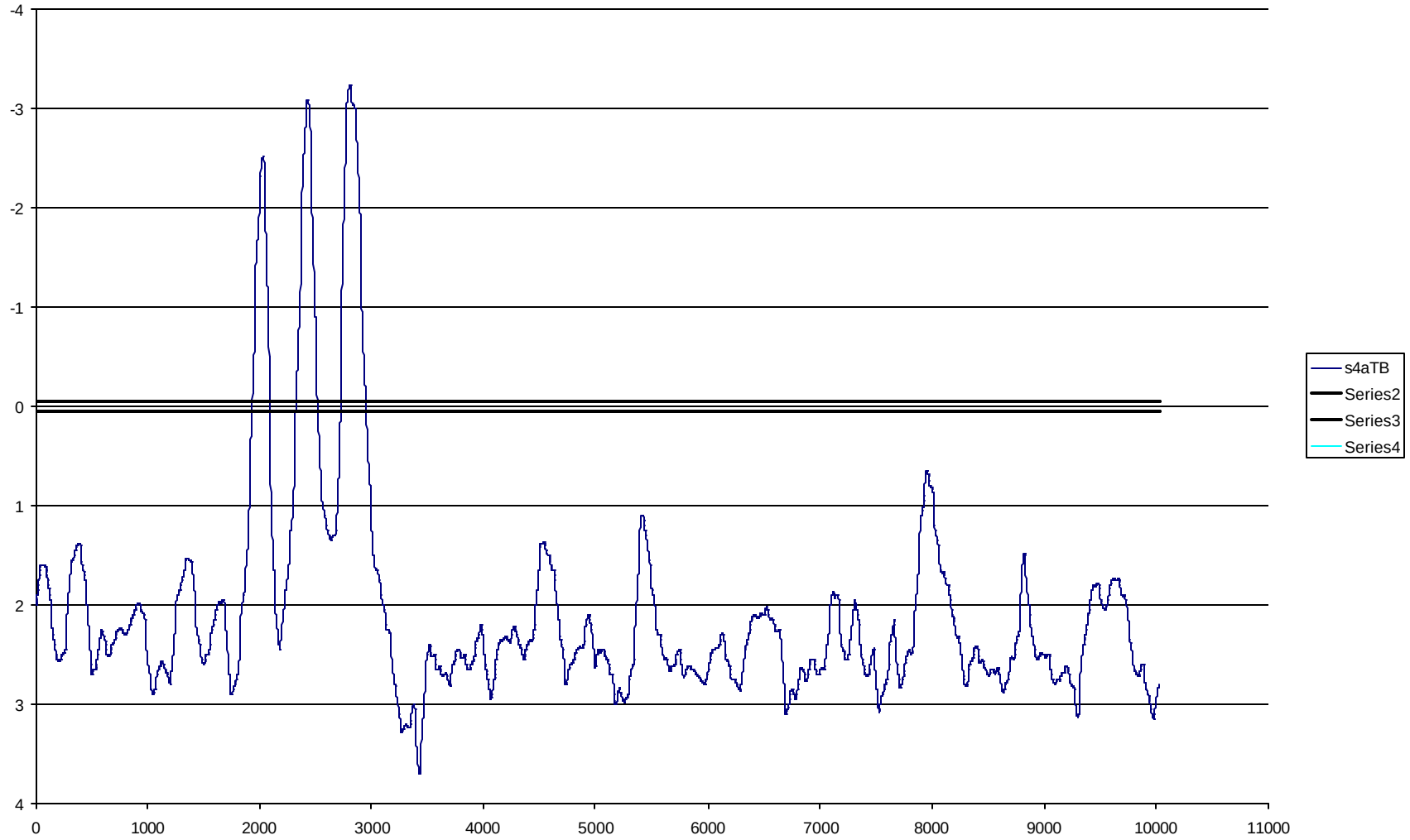

Figure A20: Lane position (in meters relative to center of road) for S4 driving for 10 km under Condition TB.

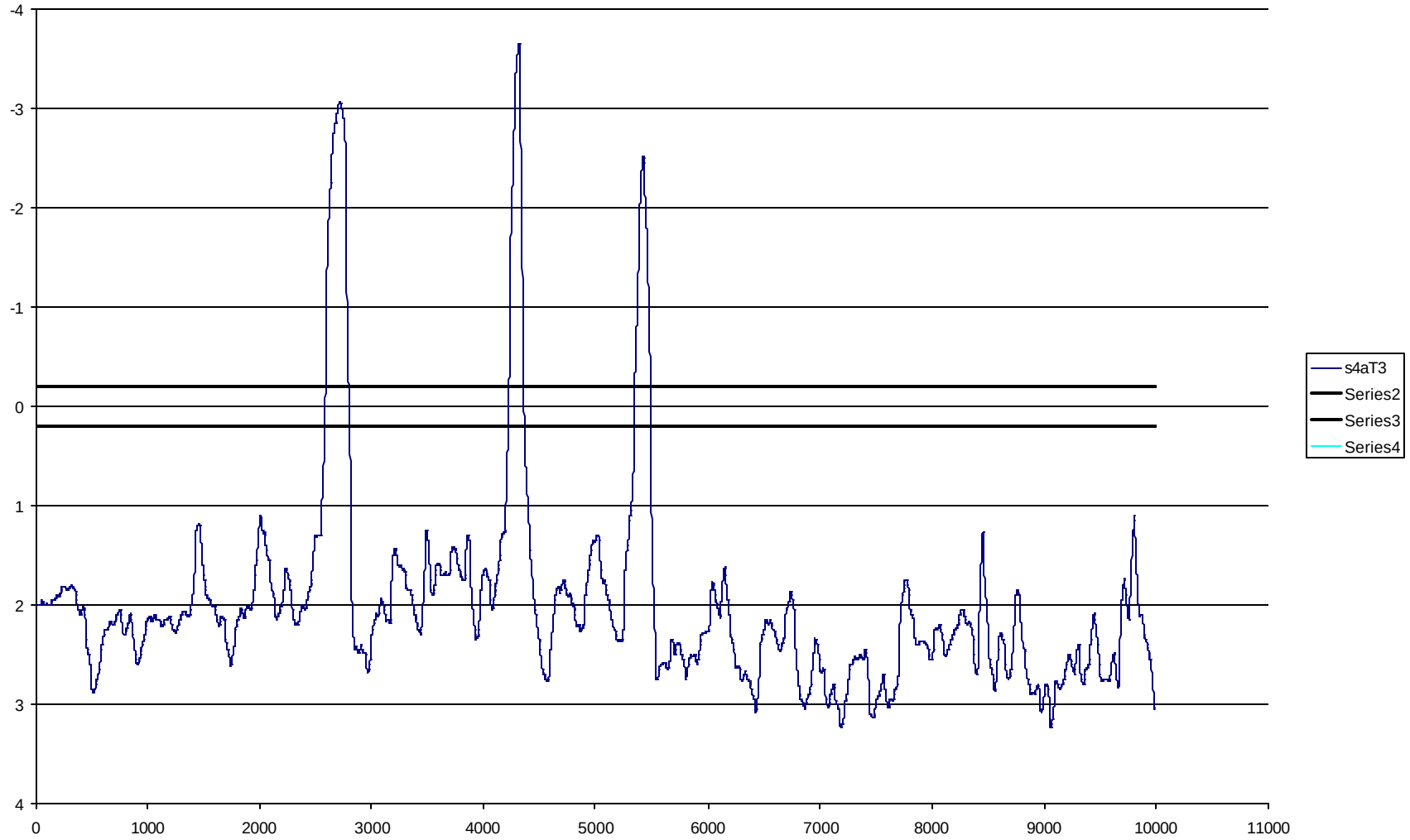

Figure A21: Lane position (in meters relative to center of road) for S4 driving for 10 km under Condition T3.

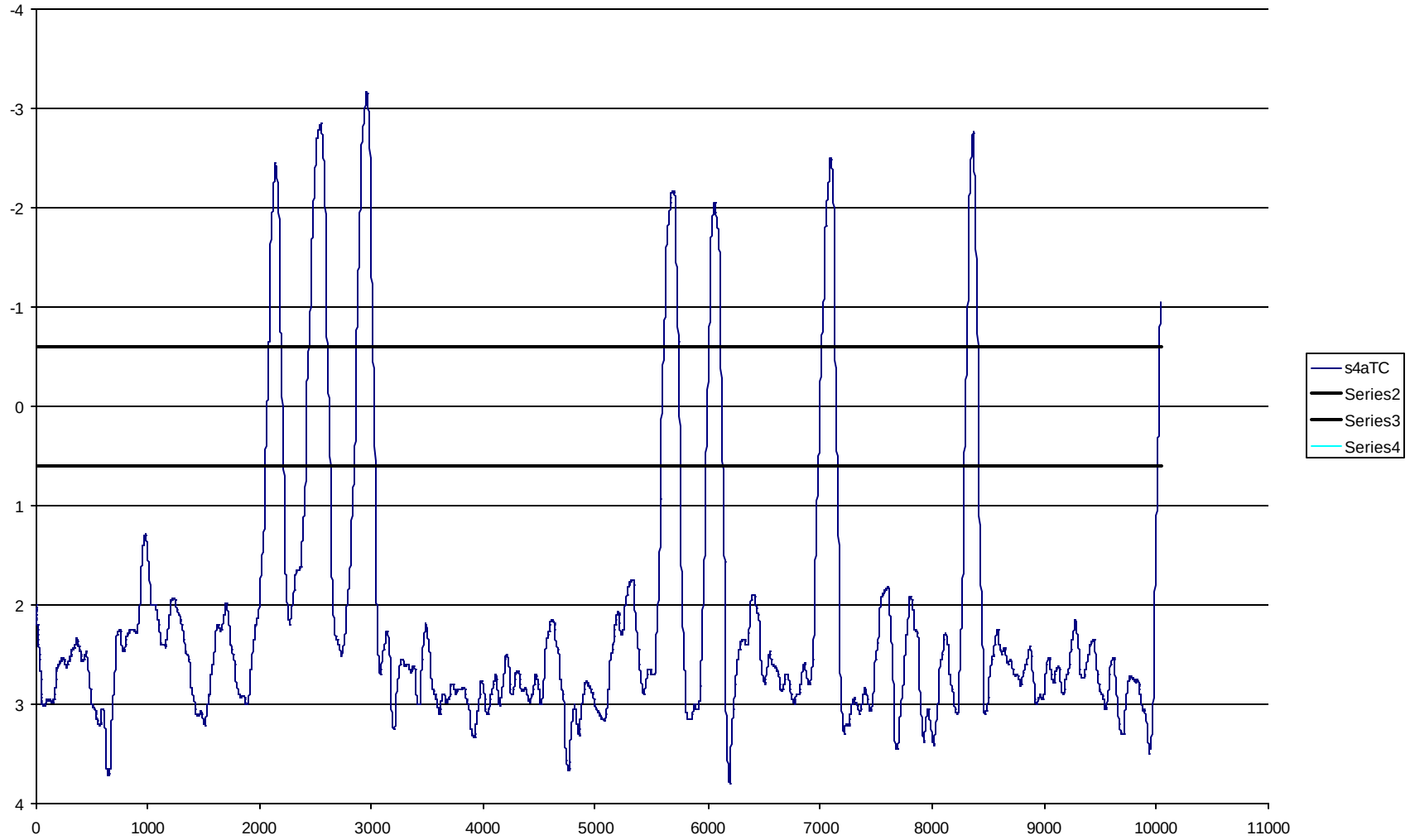

Figure A22: Lane position (in meters relative to center of road) for S4 driving for 10 km under Condition TC.

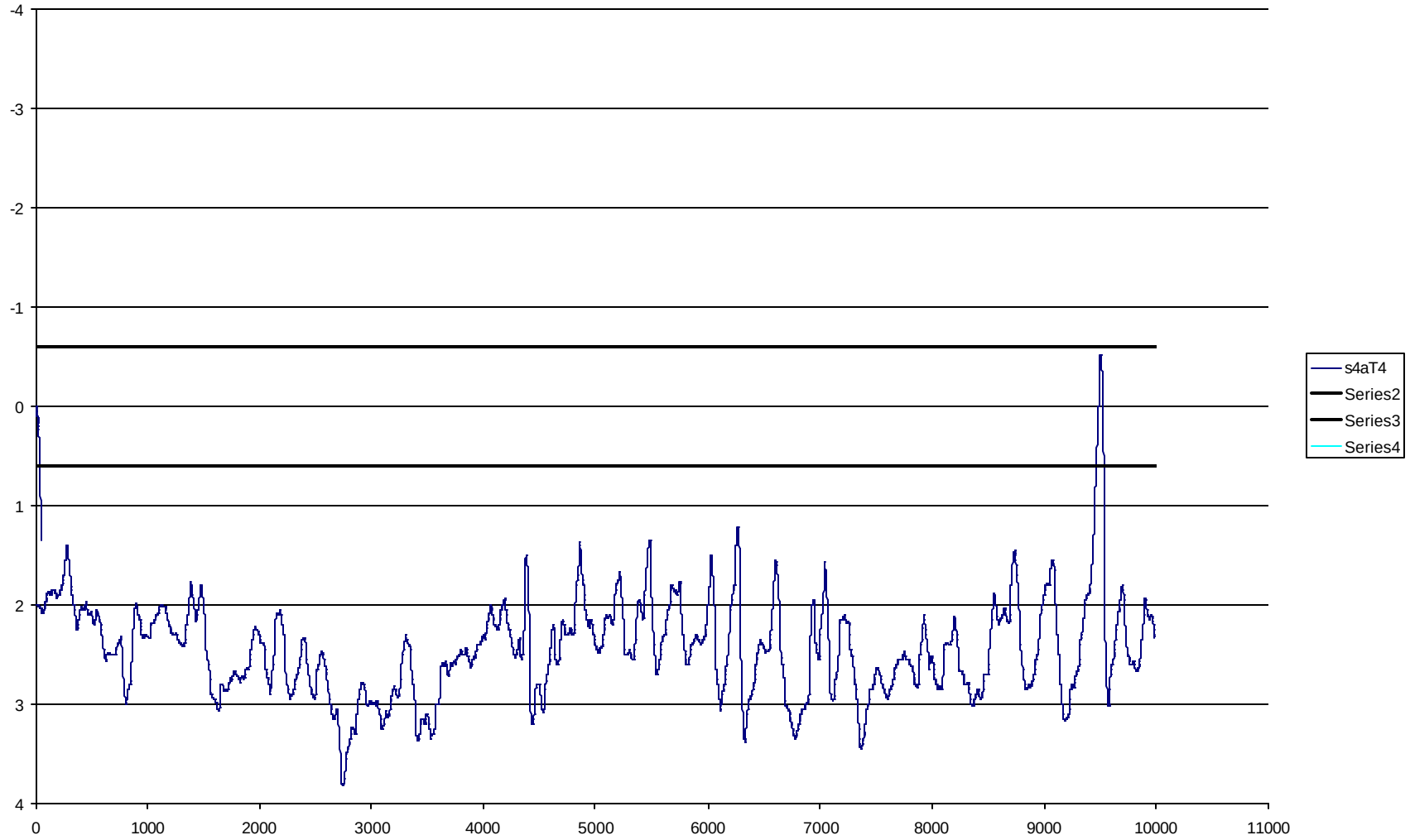

Figure A23: Lane position (in meters relative to center of road) for S4 driving for 10 km under Condition T4.

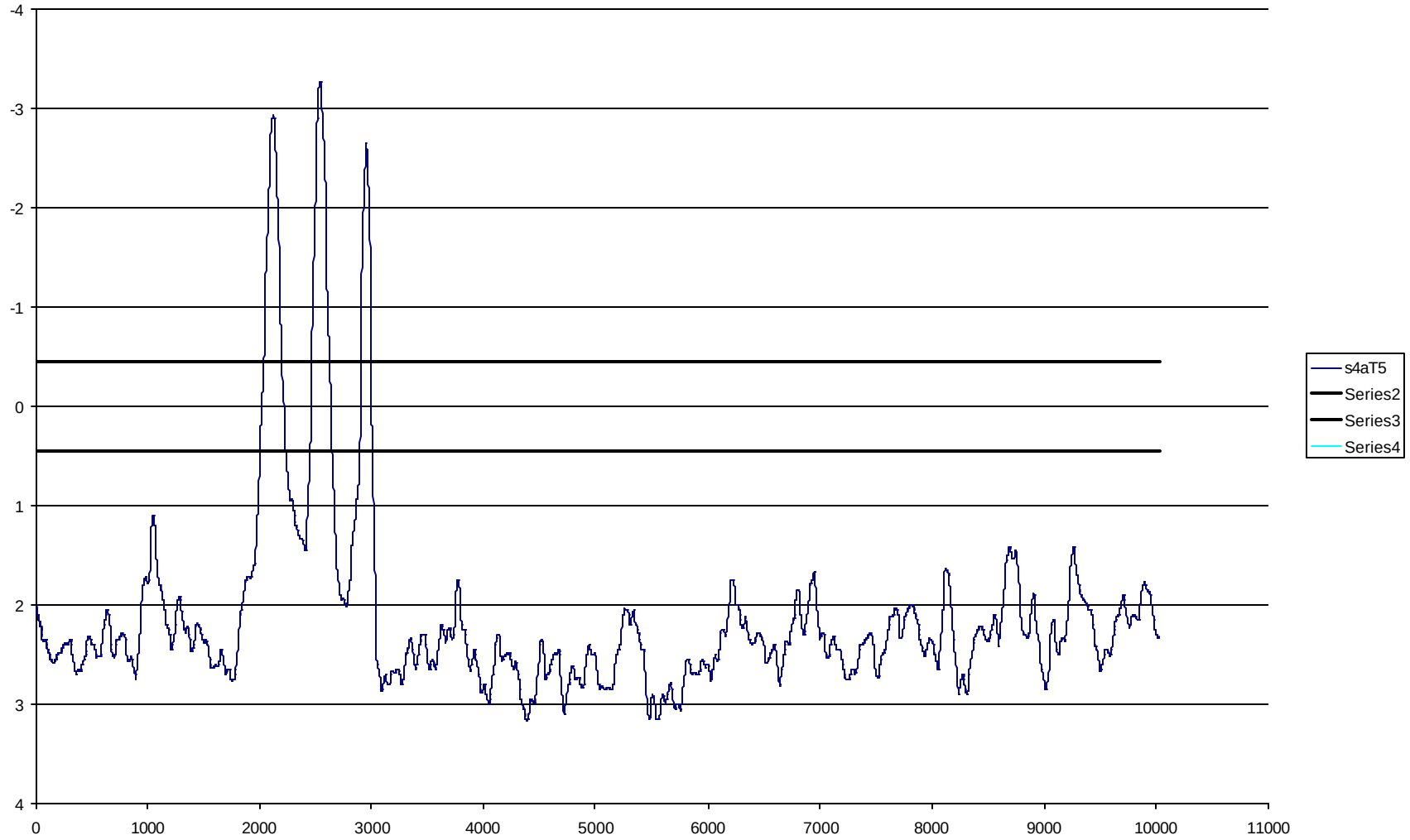

Figure A24: Lane position (in meters relative to center of road) for S4 driving for 10 km under Condition T5.

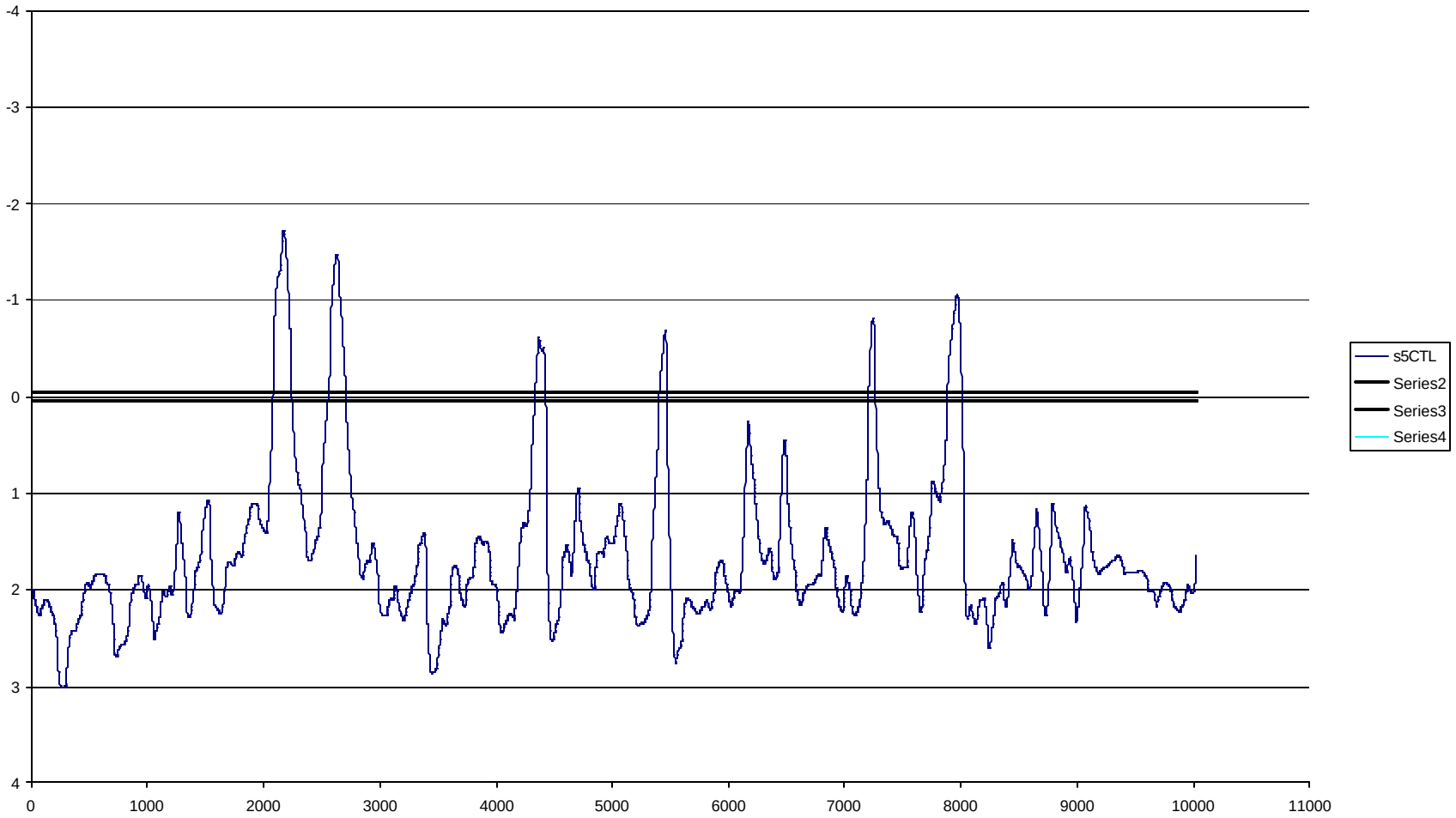

Figure A25: Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition CTL.

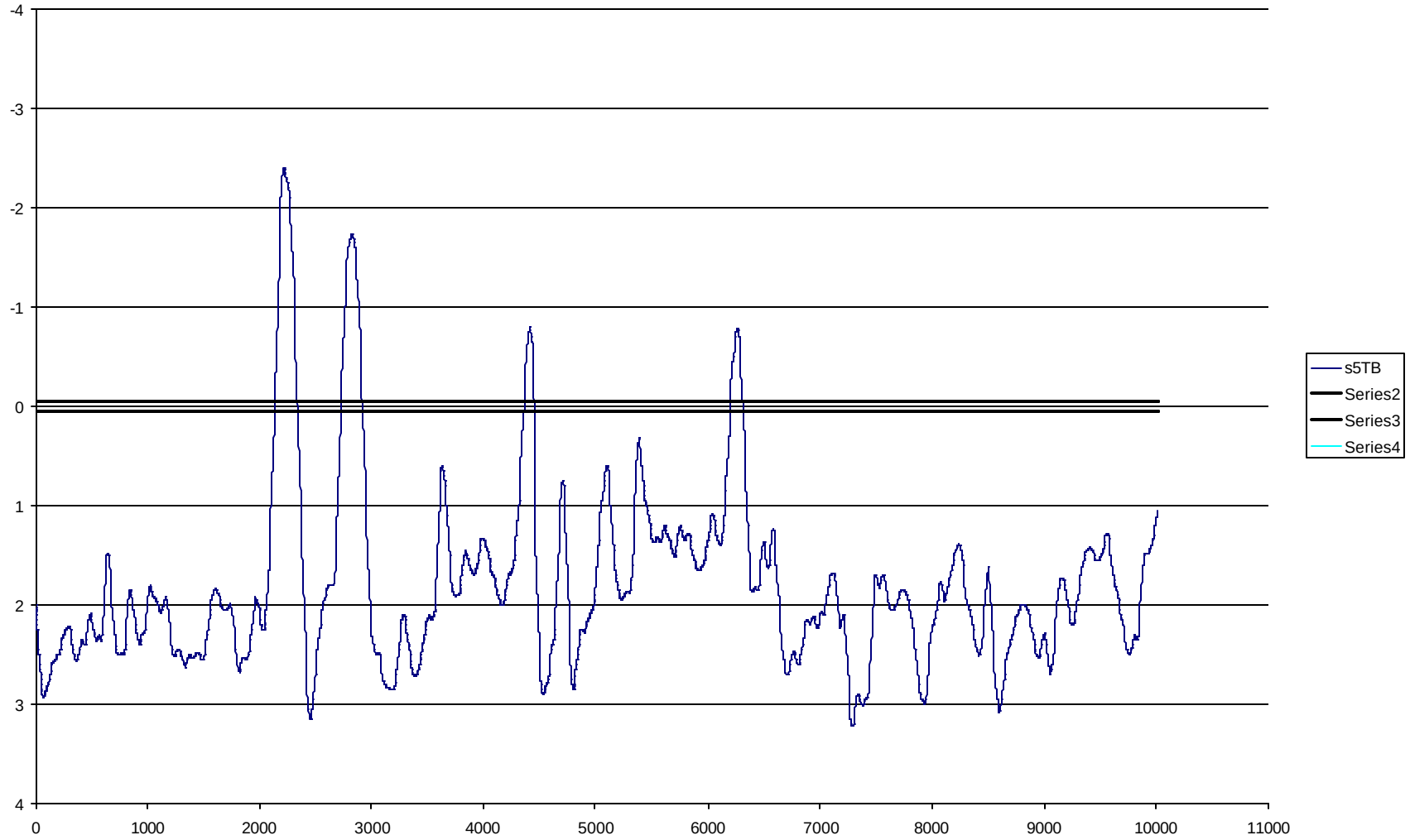

Figure A26: Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition TB.

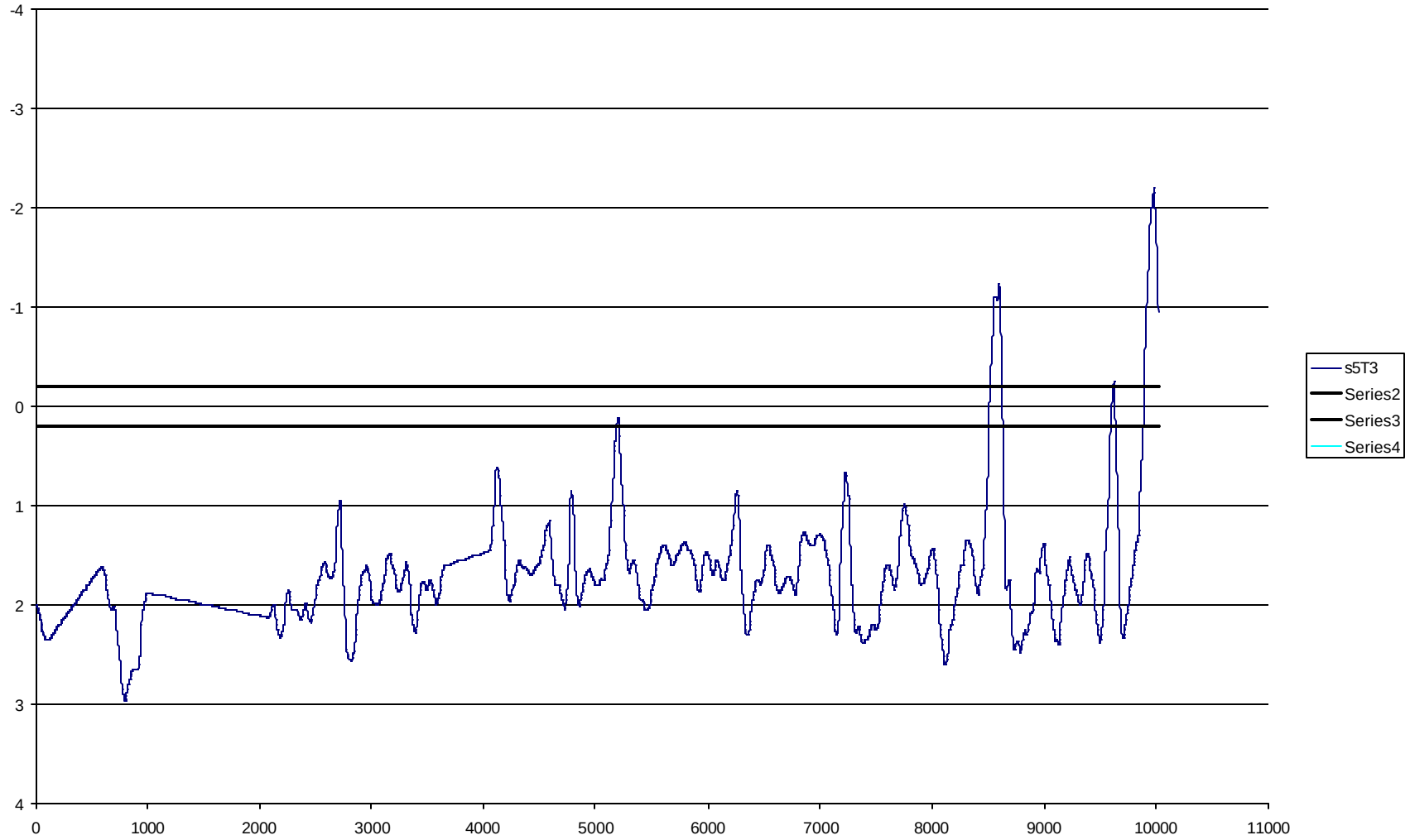

Figure A27: Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition T3.

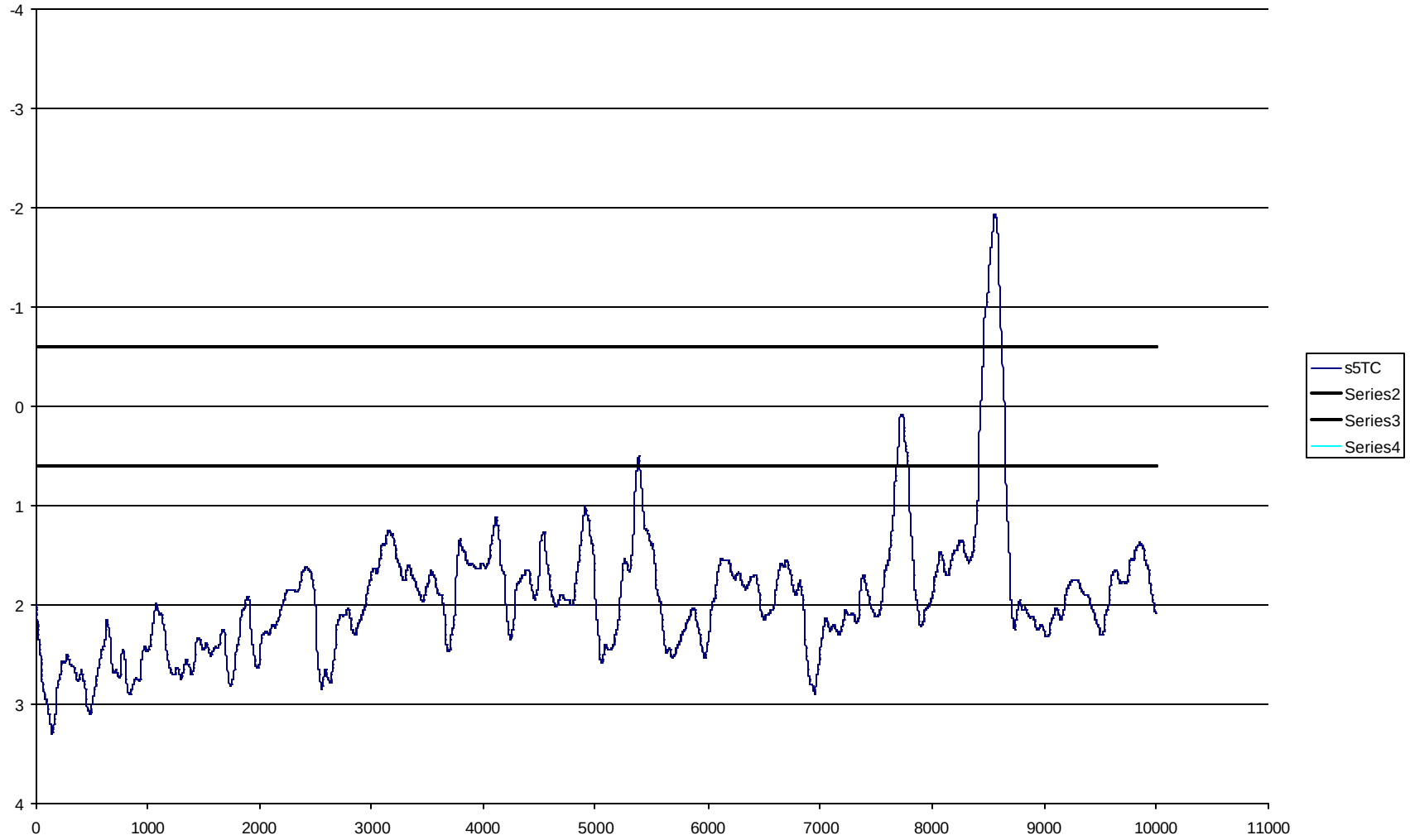

Figure A28: Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition TC.

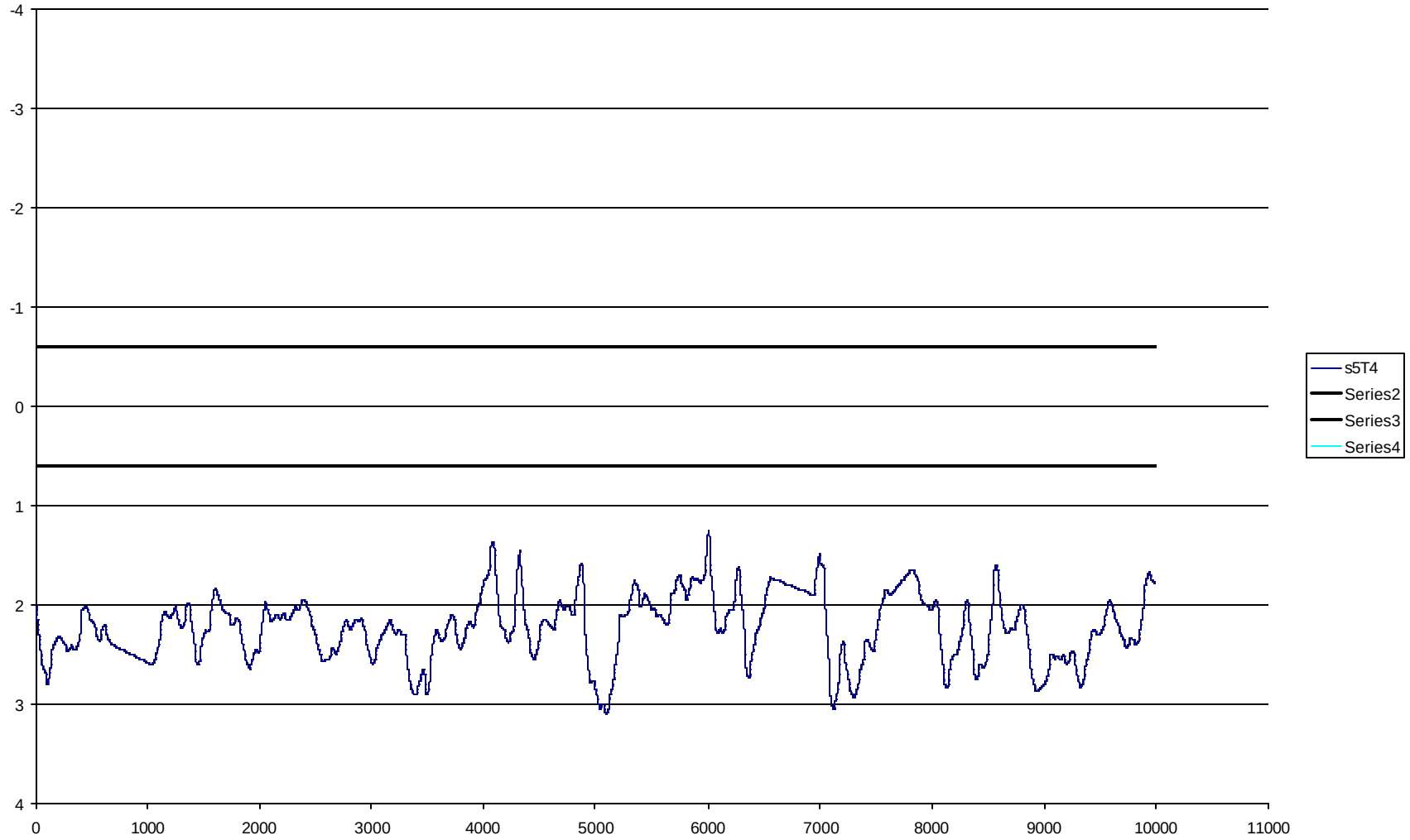

Figure A29: Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition T4.

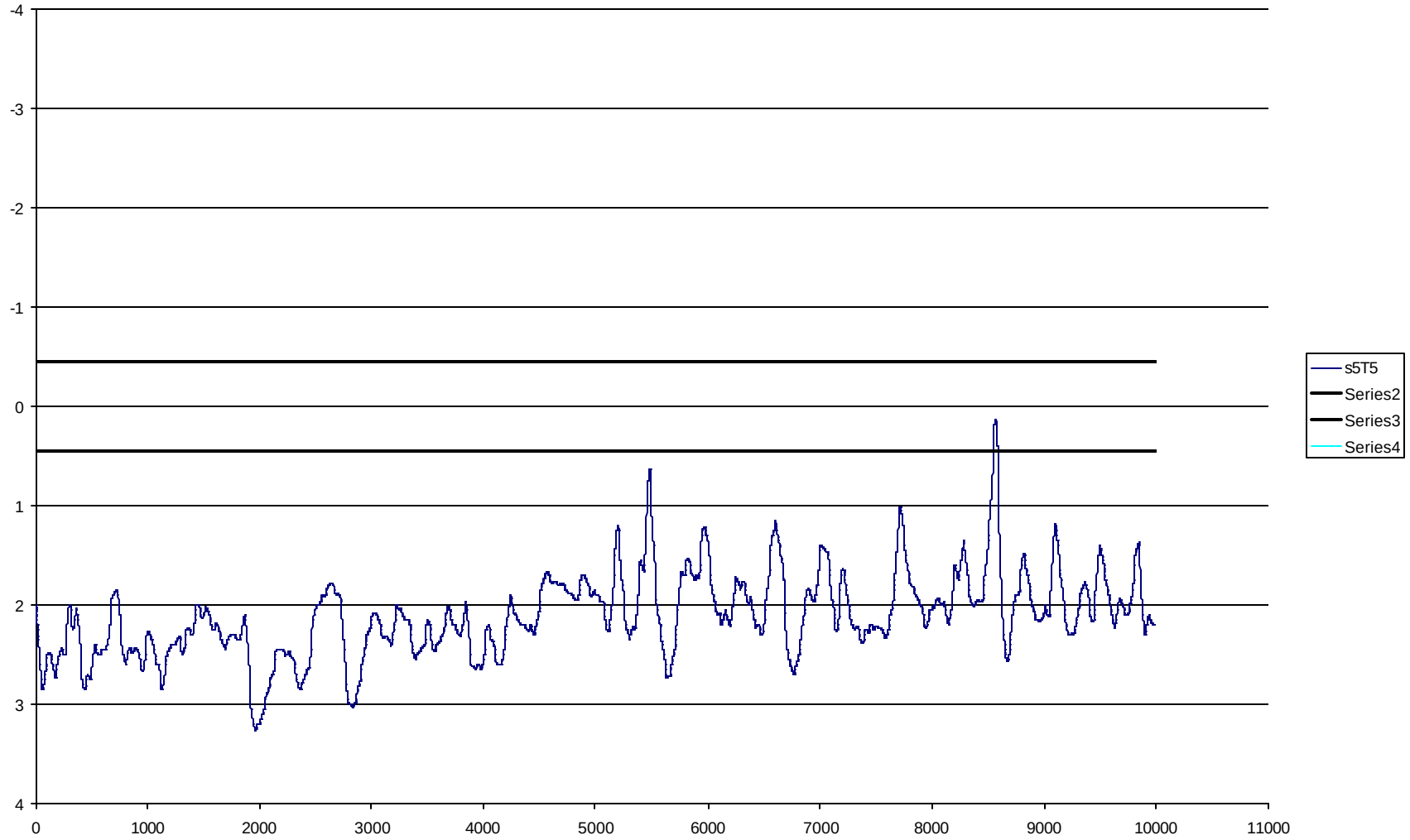

Figure A30: Lane position (in meters relative to center of road) for S5 driving for 10 km under Condition T5.

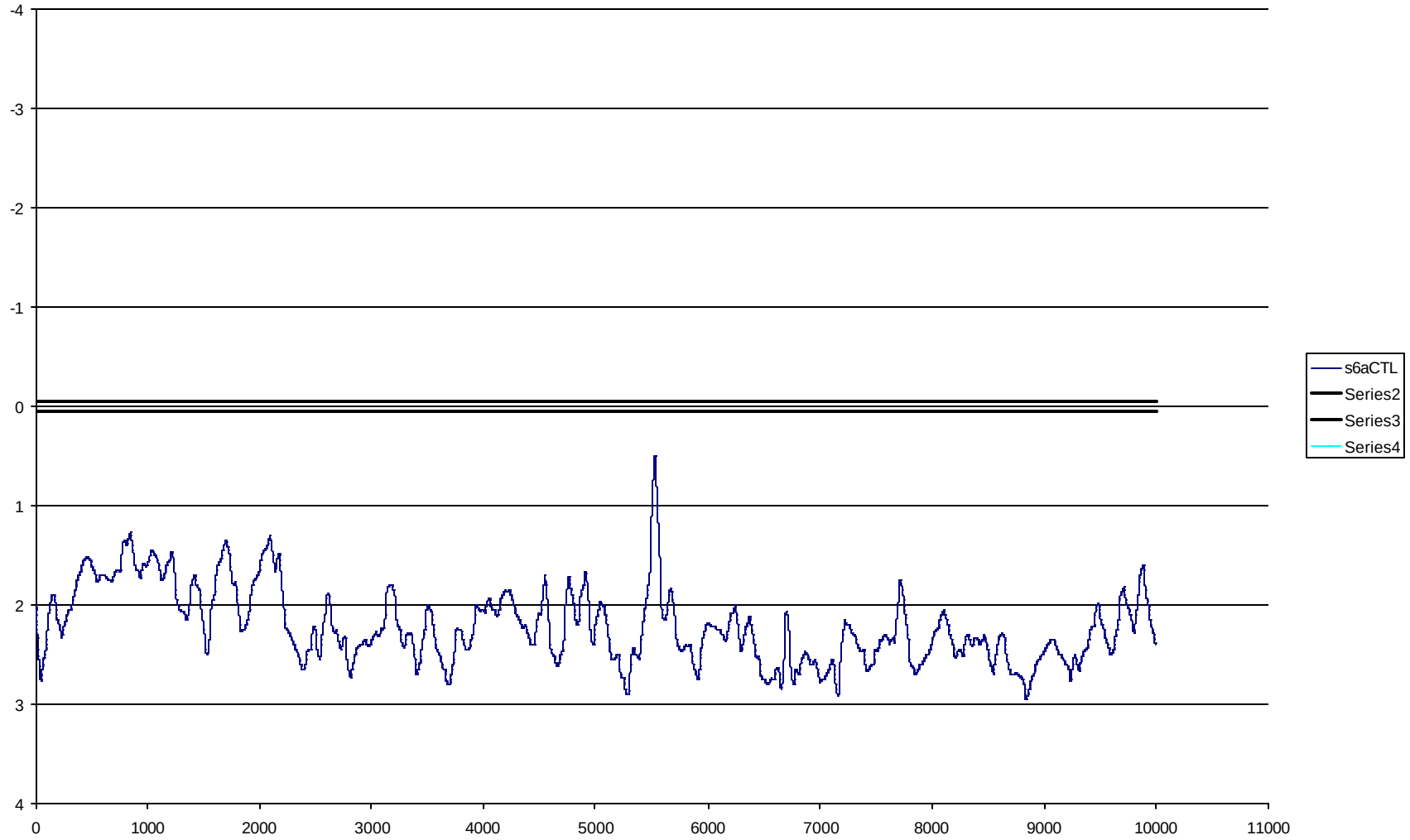

Figure A31: Lane position (in meters relative to center of road) for S6 driving for 10 km under Condition CTL.

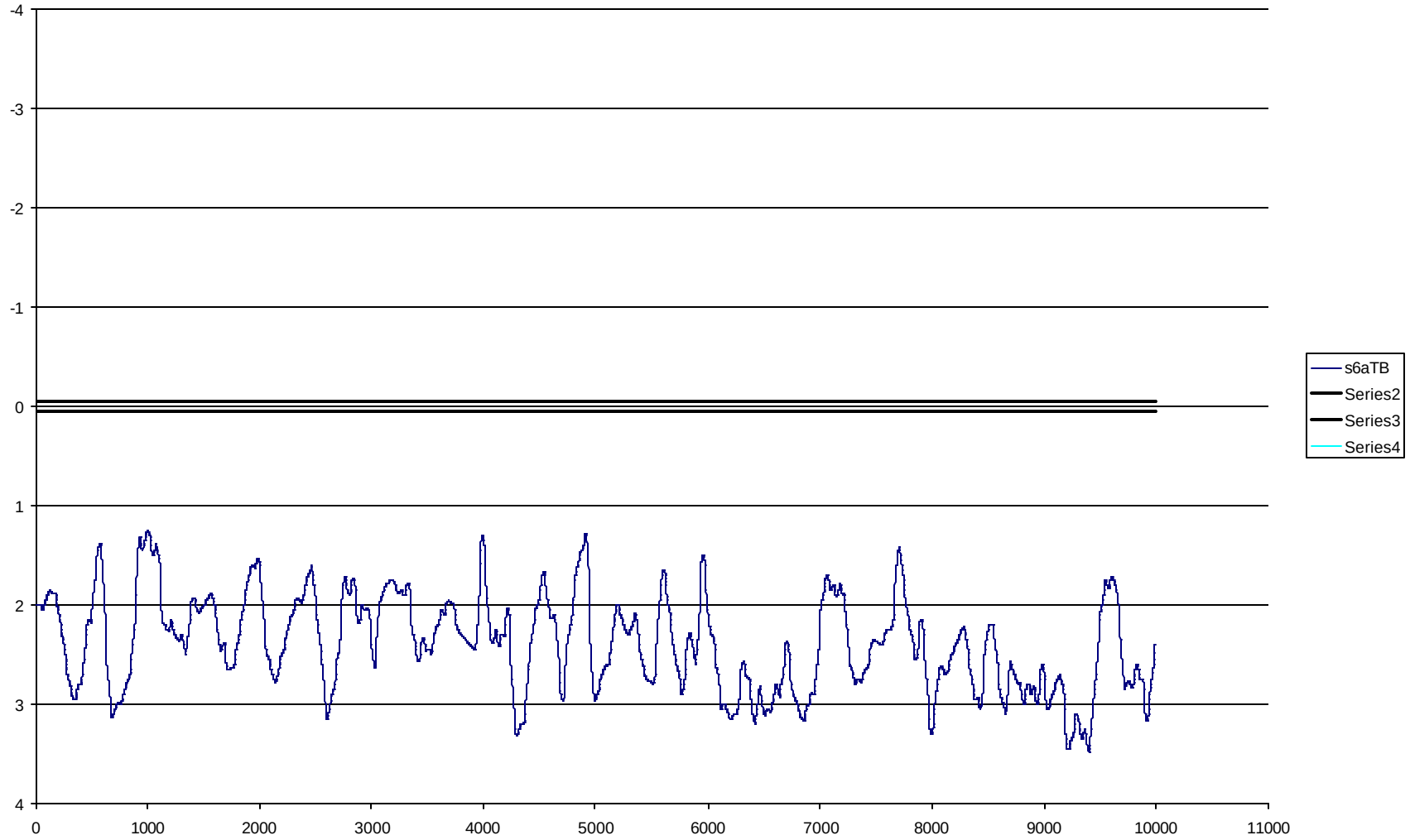

Figure A32: Lane position (in meters relative to center of road) for S6 driving for 10 km under Condition TB.

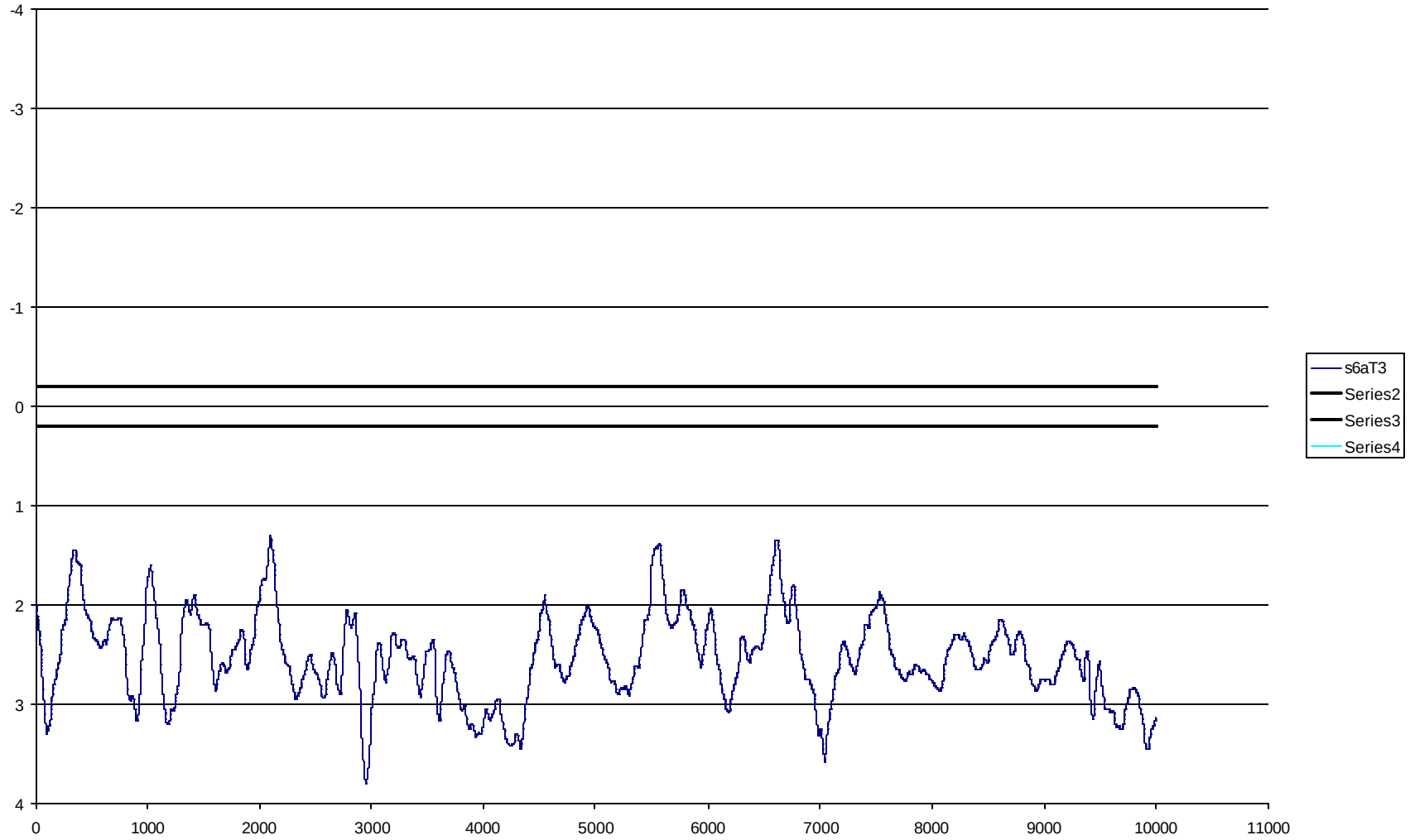

Figure A33: Lane position (in meters relative to center of road) for S6 driving for 10 km under Condition T3.

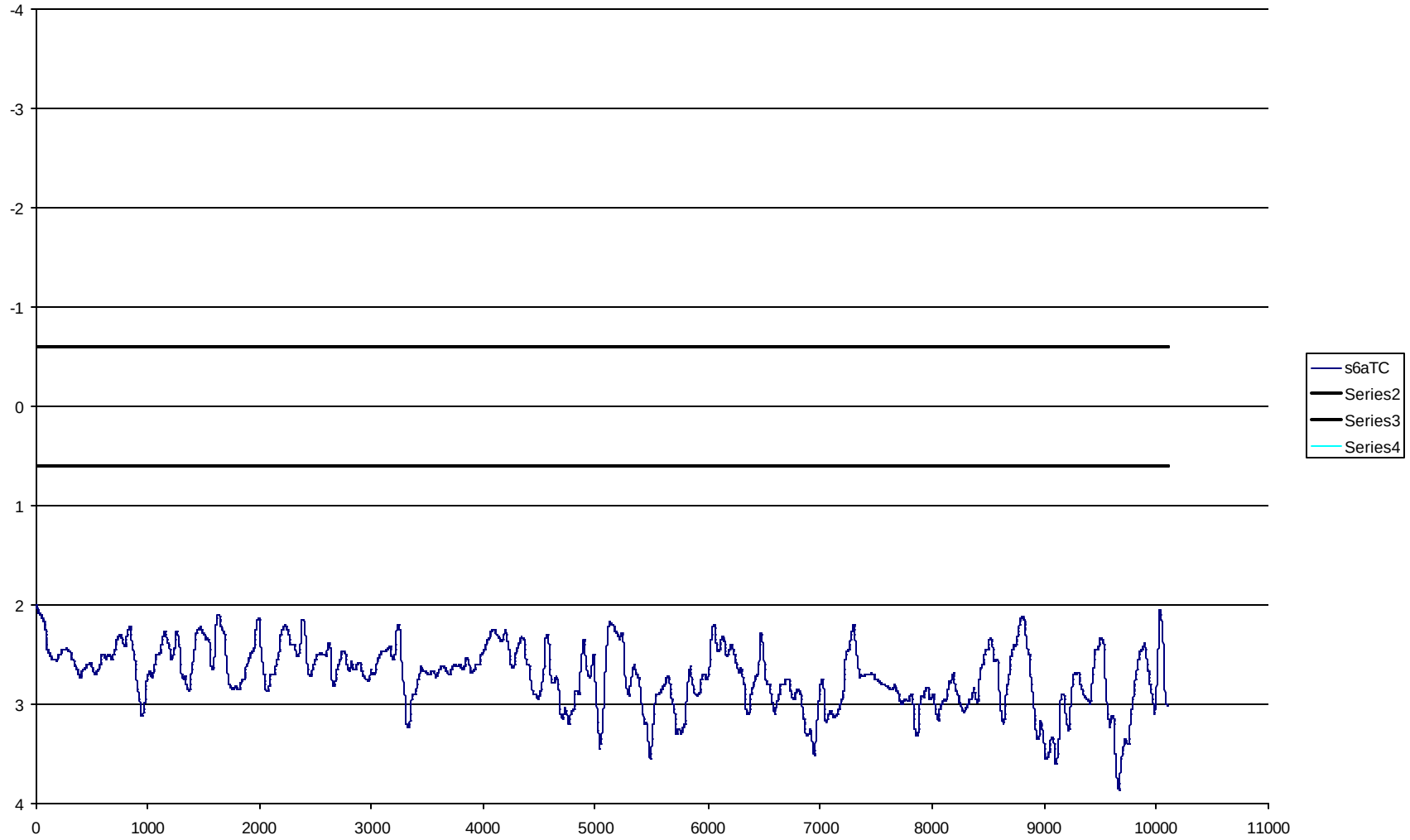

Figure A34: Lane position (in meters relative to center of road) for S6 driving for 10 km under Condition TC.

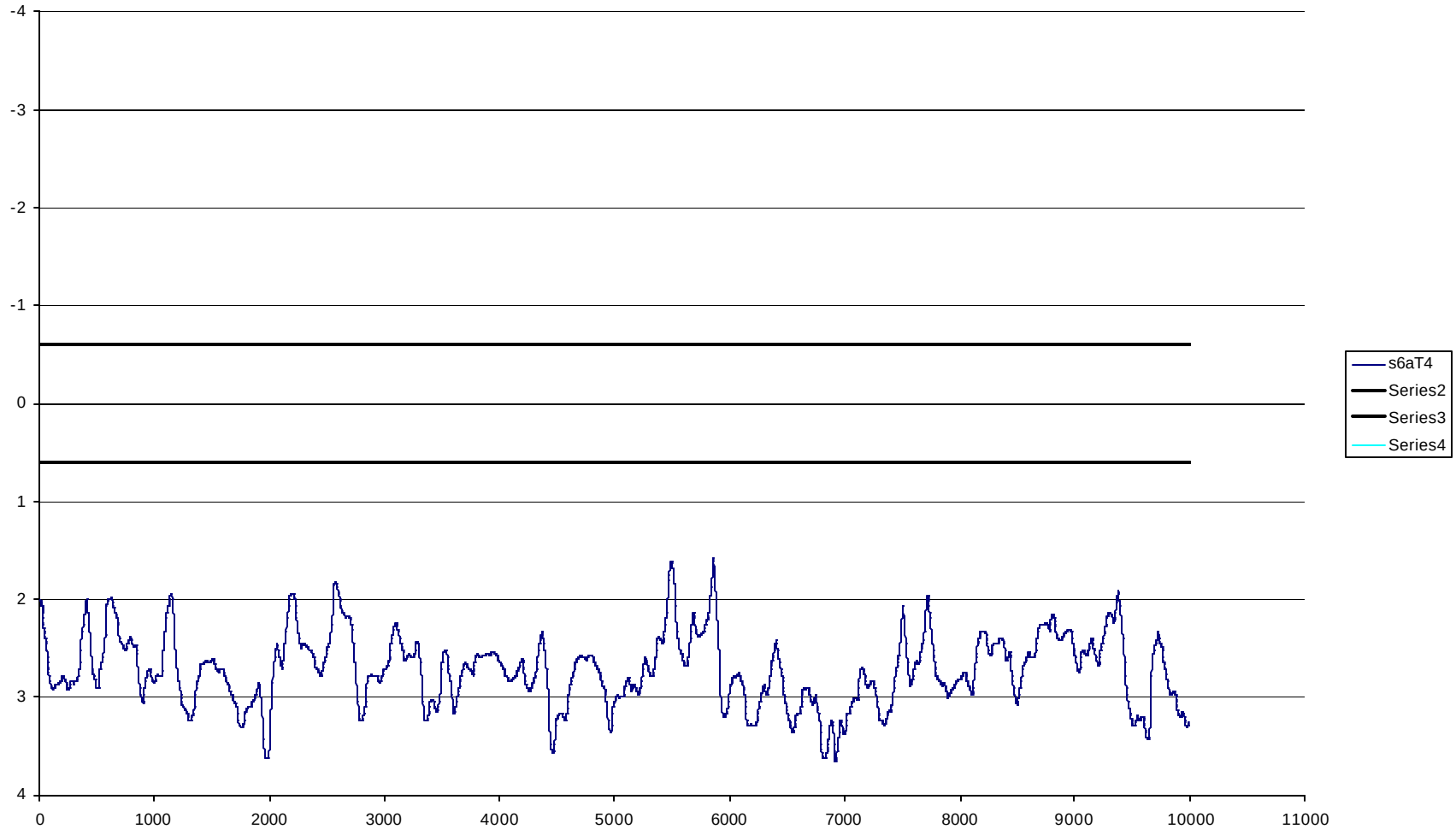

Figure A35: Lane position (in meters relative to center of road) for S6 driving for 10 km under Condition T4.

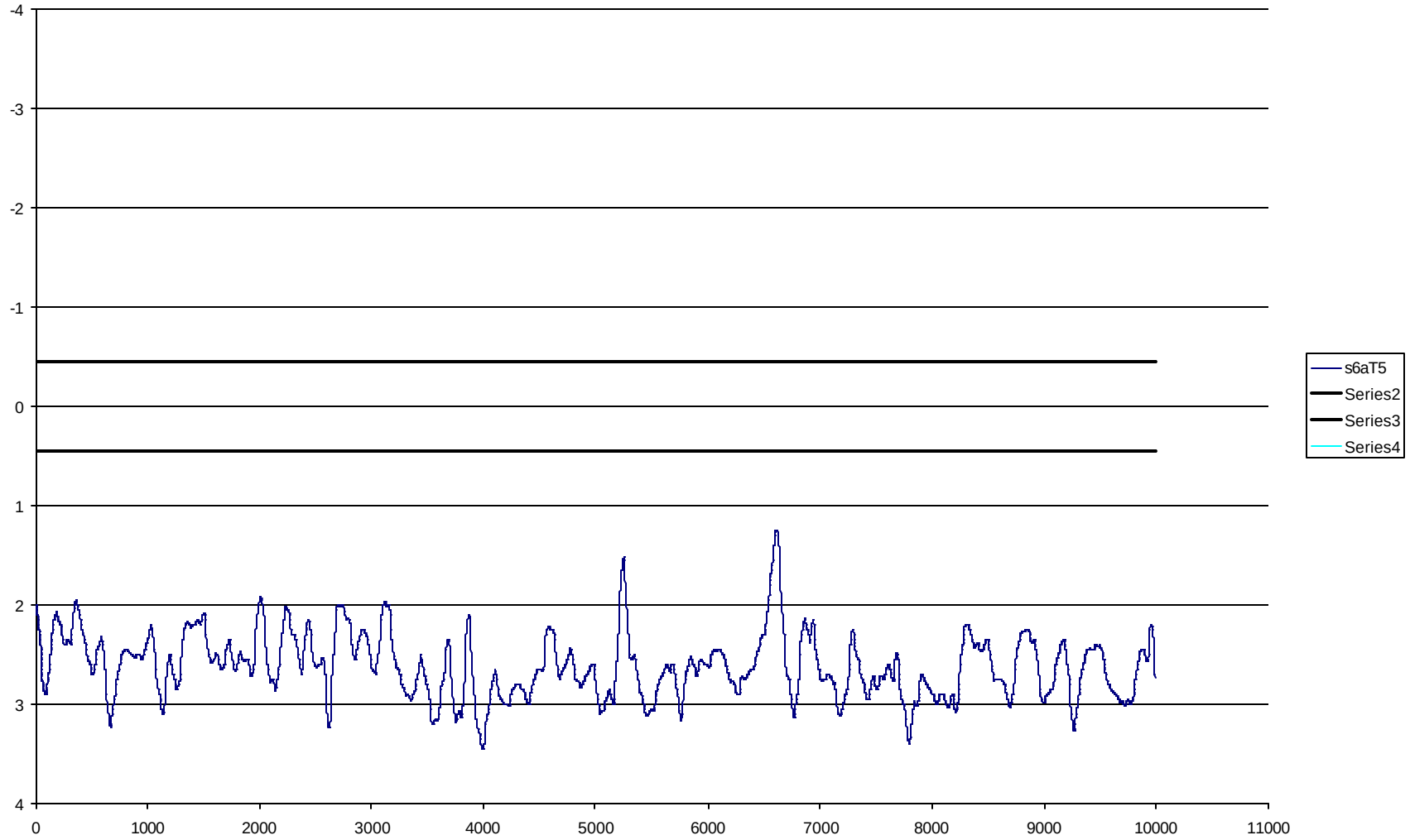

Figure A36: Lane position (in meters relative to center of road) for S6 driving for 10 km under Condition T5.

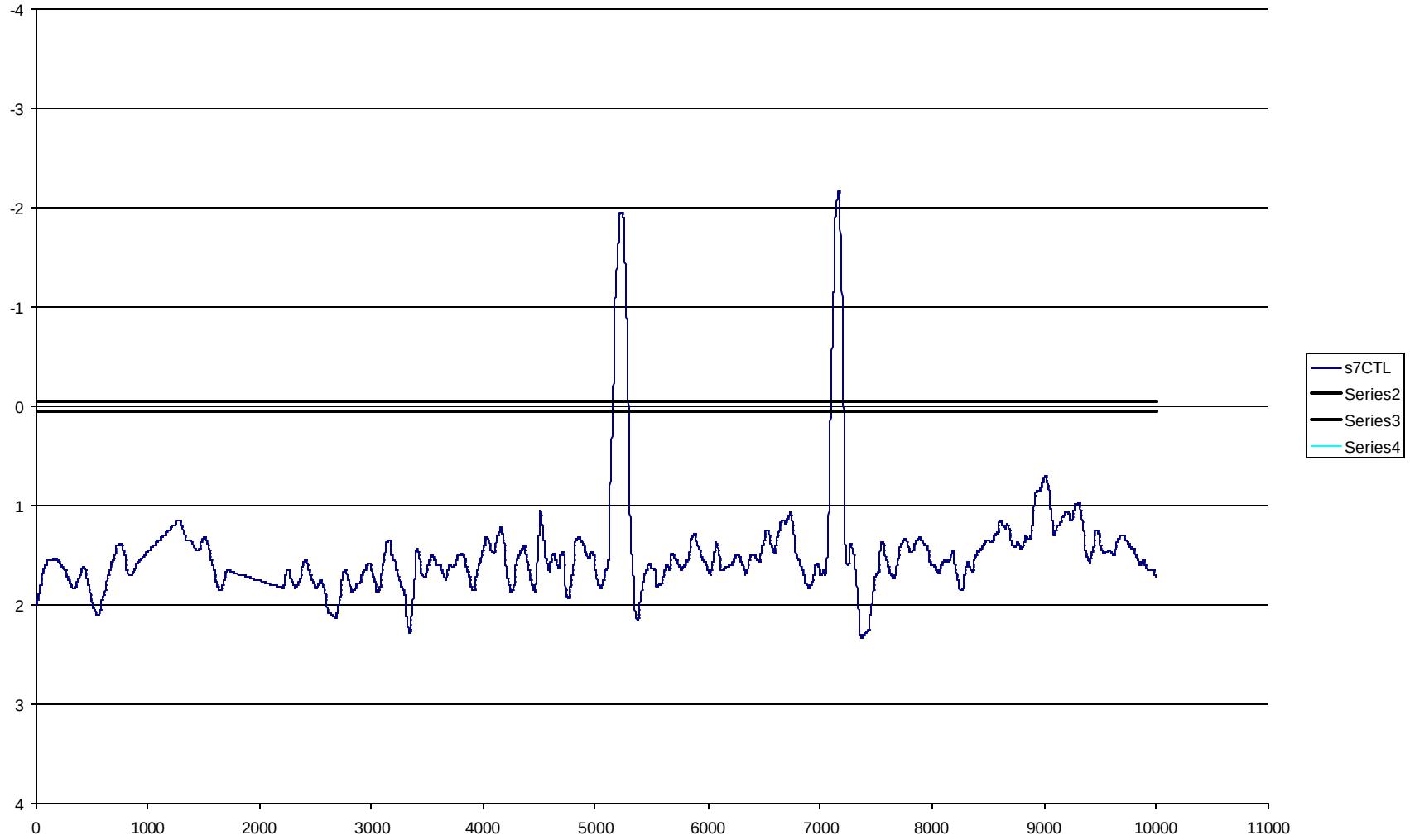

Figure A37: Lane position (in meters relative to center of road) for S7 driving for 10 km under Condition CTL.

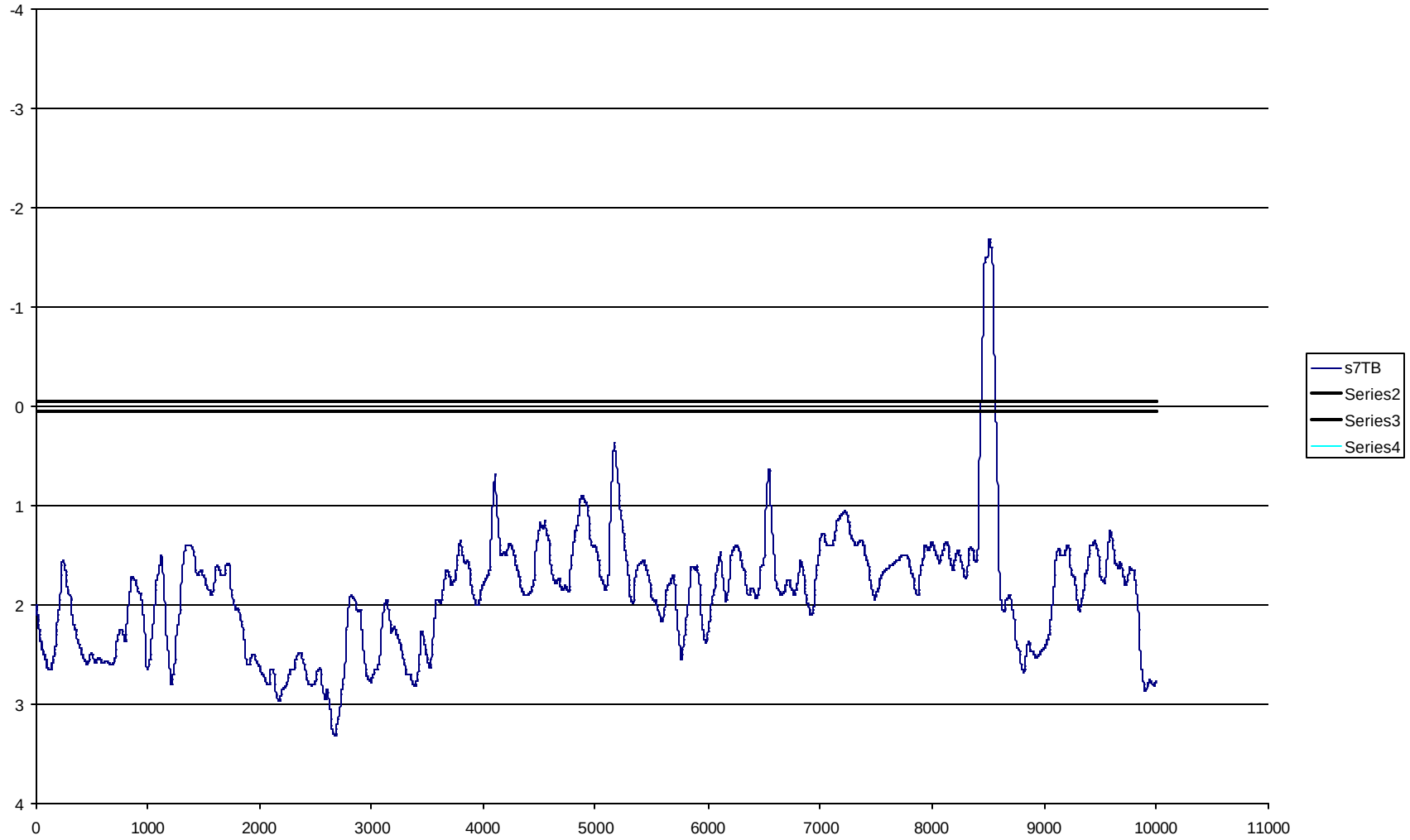

Figure A38: Lane position (in meters relative to center of road) for S7 driving for 10 km under Condition TB.

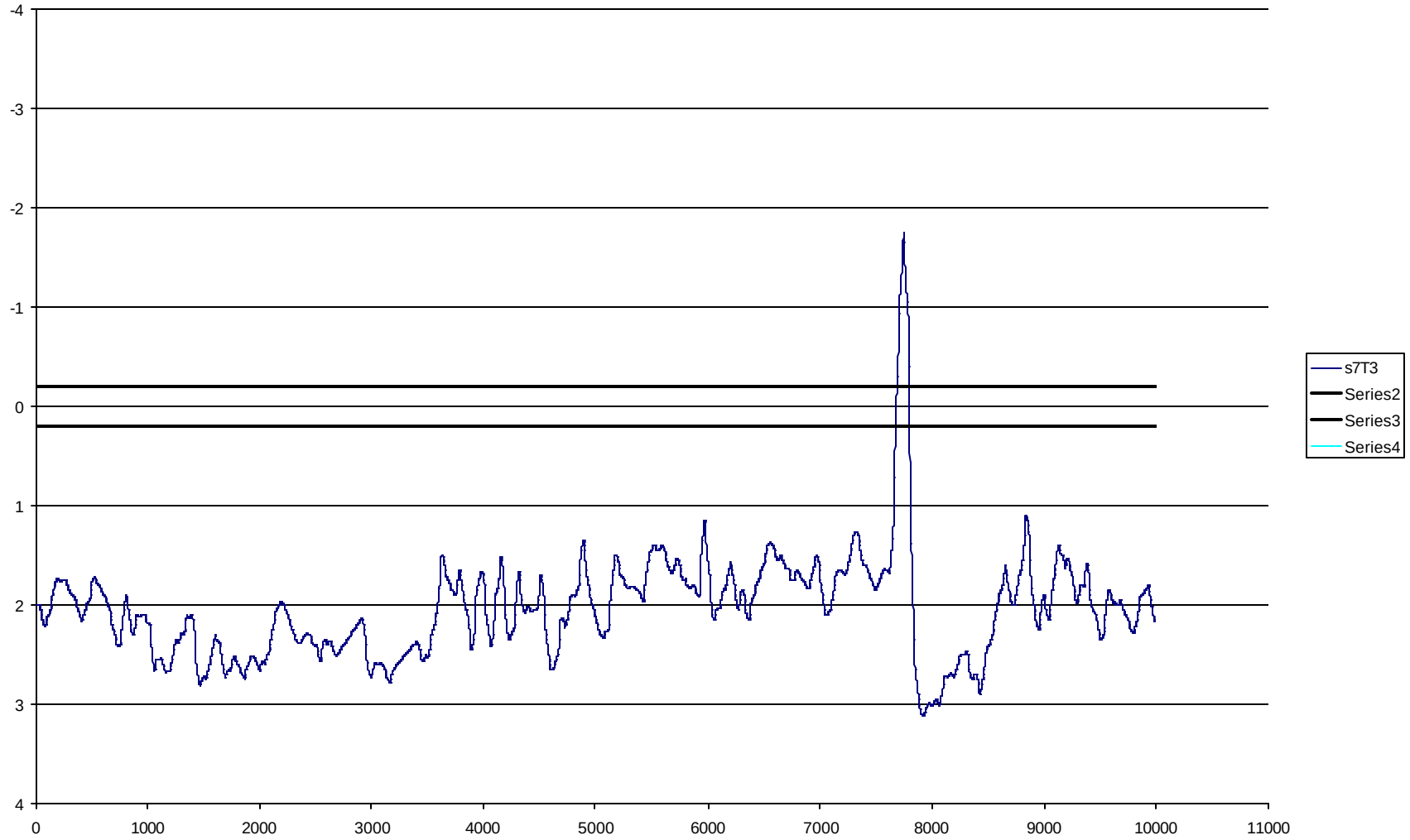

Figure A39: Lane position (in meters relative to center of road) for S7 driving for 10 km under Condition T3.

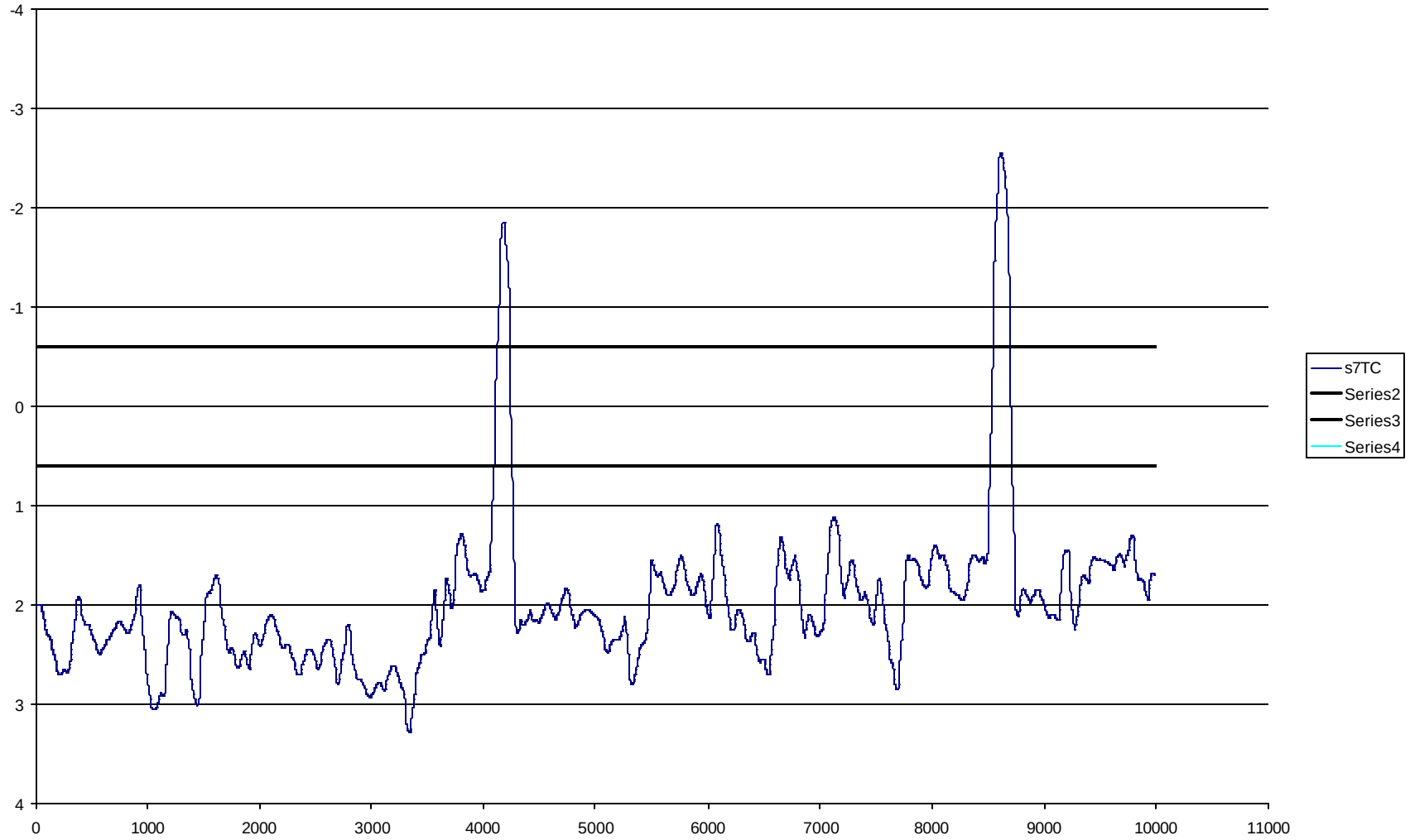

Figure A40: Lane position (in meters relative to center of road) for S7 driving for 10 km under Condition TC.

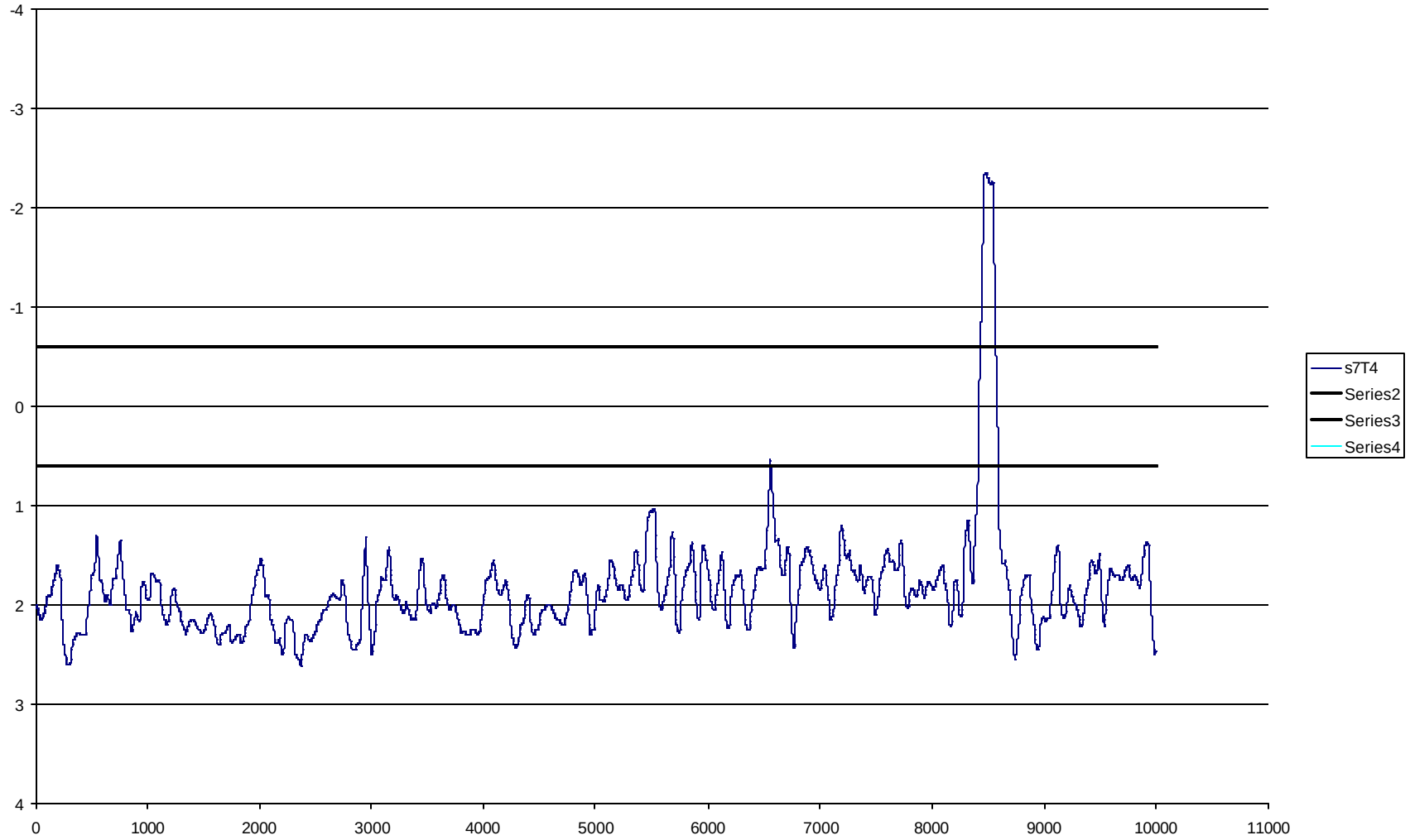

Figure A41: Lane position (in meters relative to center of road) for S7 driving for 10 km under Condition T4.

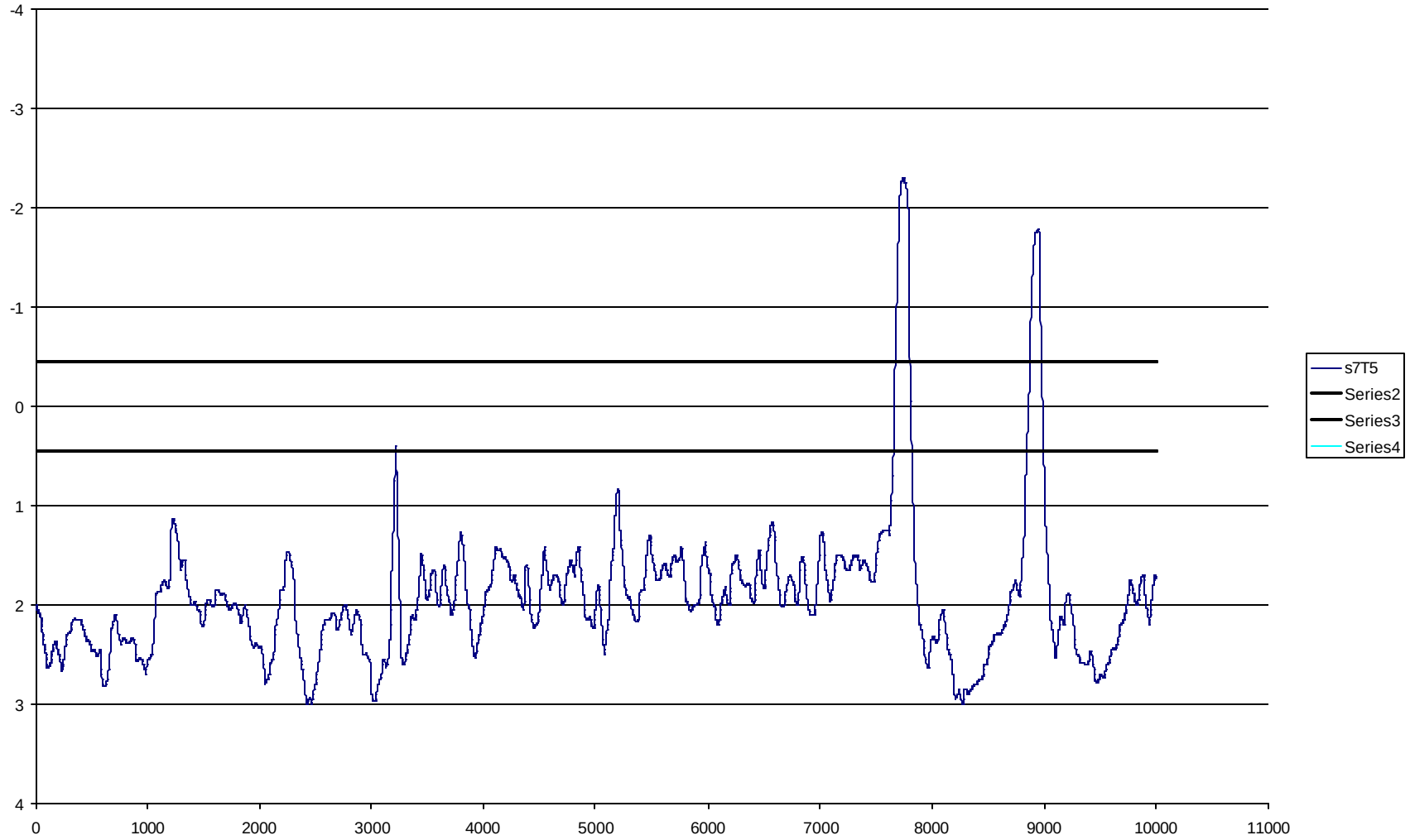

Figure A42: Lane position (in meters relative to center of road) for S7 driving for 10 km under Condition T5.

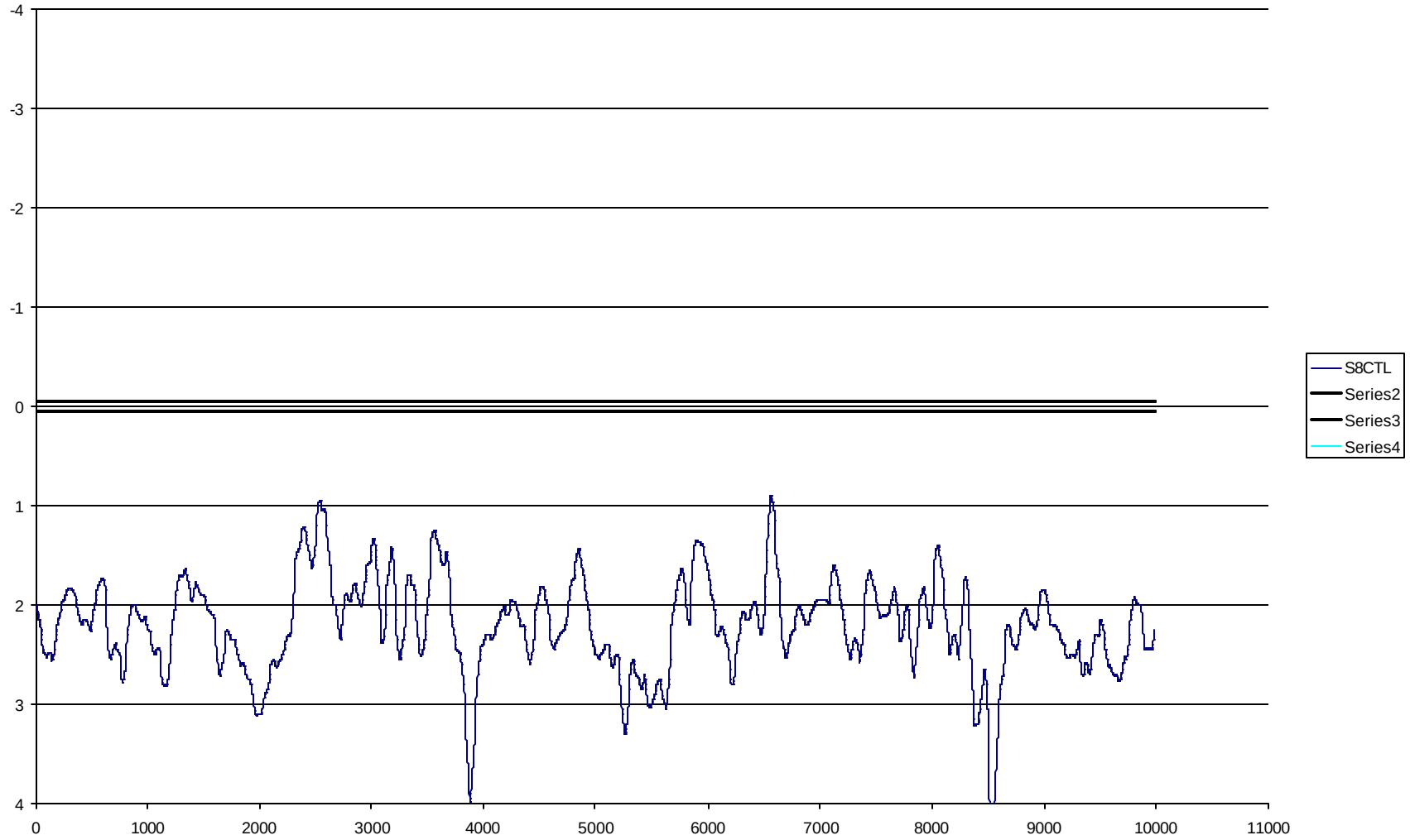

Figure A43: Lane position (in meters relative to center of road) for S8 driving for 10 km under Condition CTL.

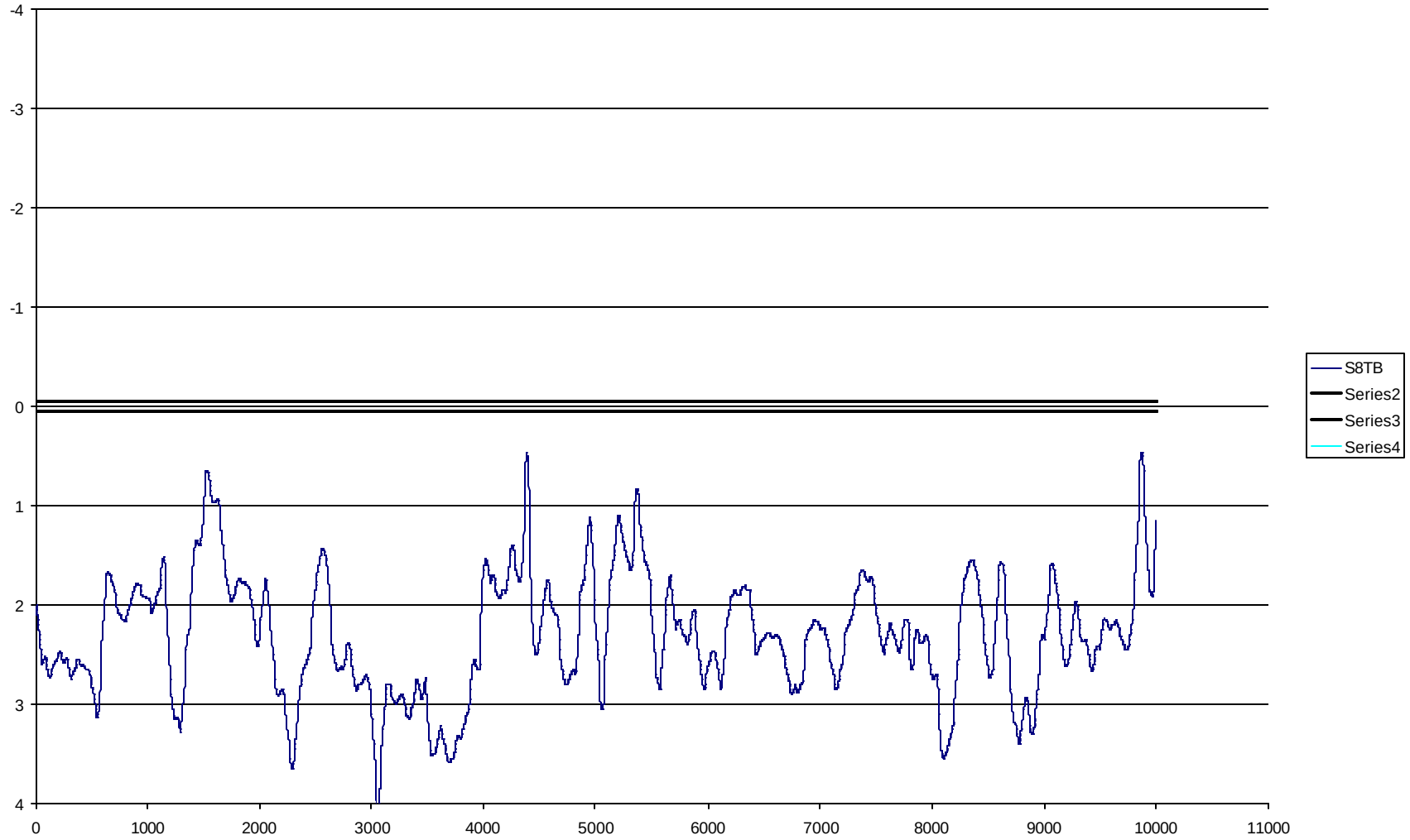

Figure A44: Lane position (in meters relative to center of road) for S8 driving for 10 km under Condition TB.

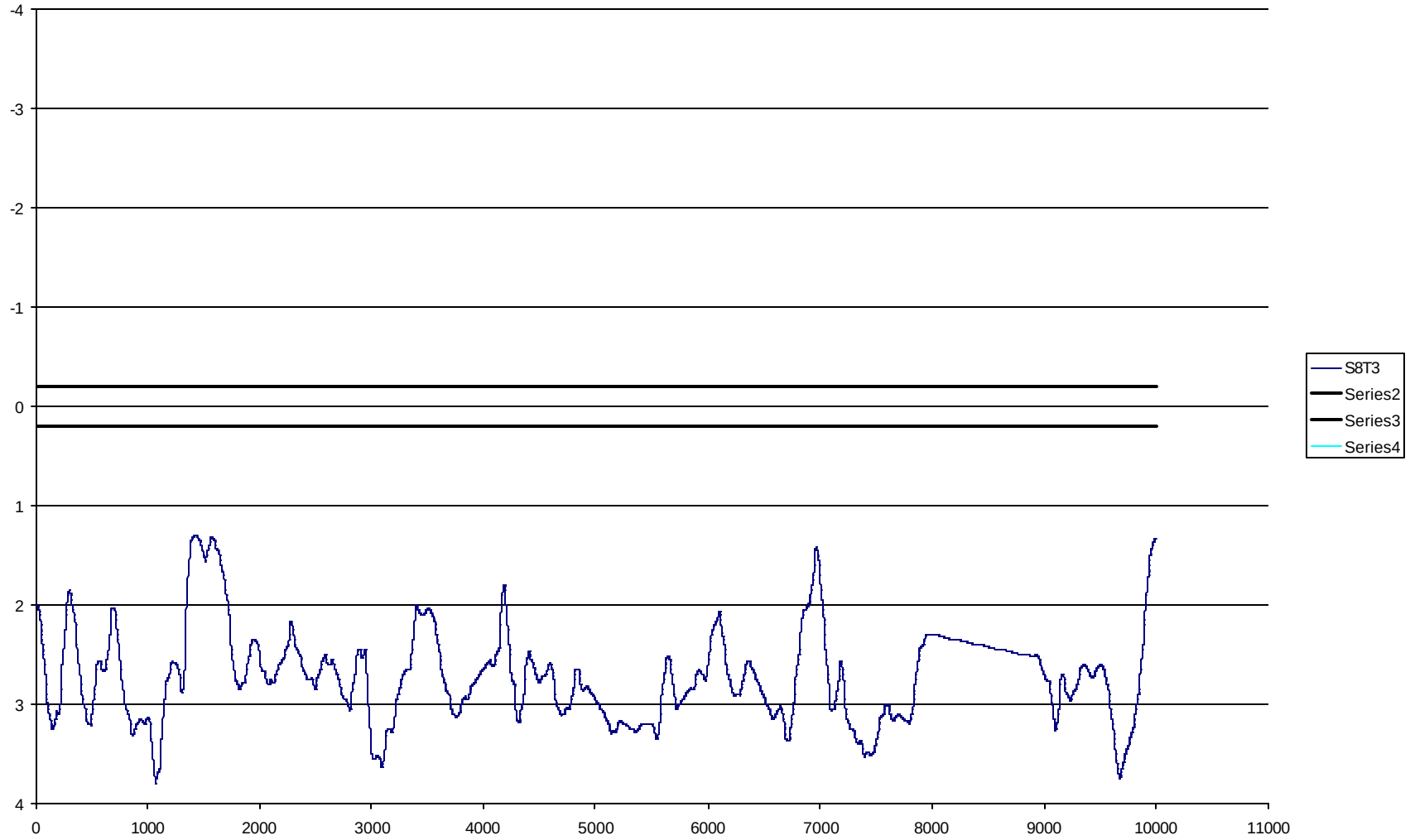

Figure A45: Lane position (in meters relative to center of road) for S8 driving for 10 km under Condition T3.

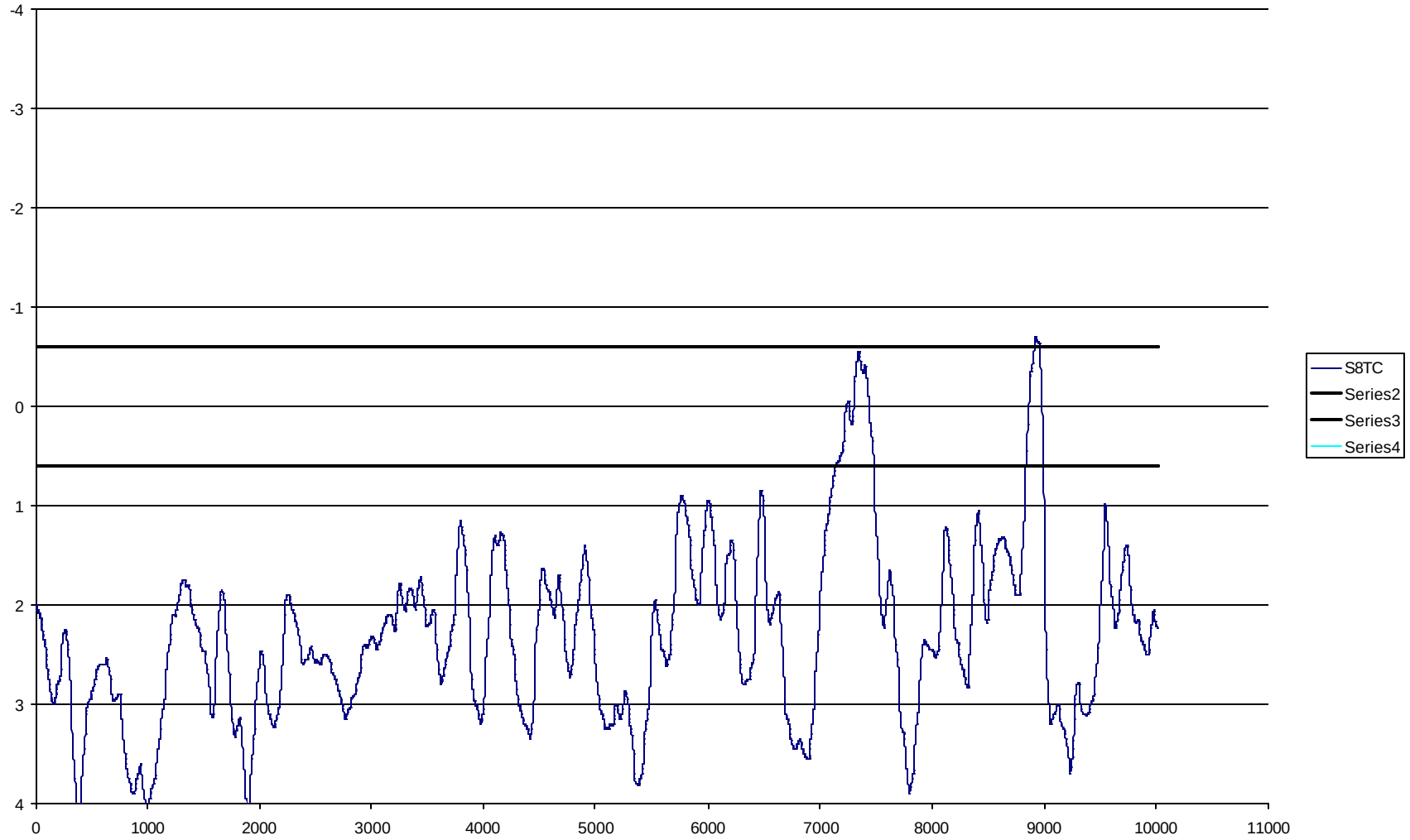

Figure A46: Lane position (in meters relative to center of road) for S8 driving for 10 km under Condition TC.

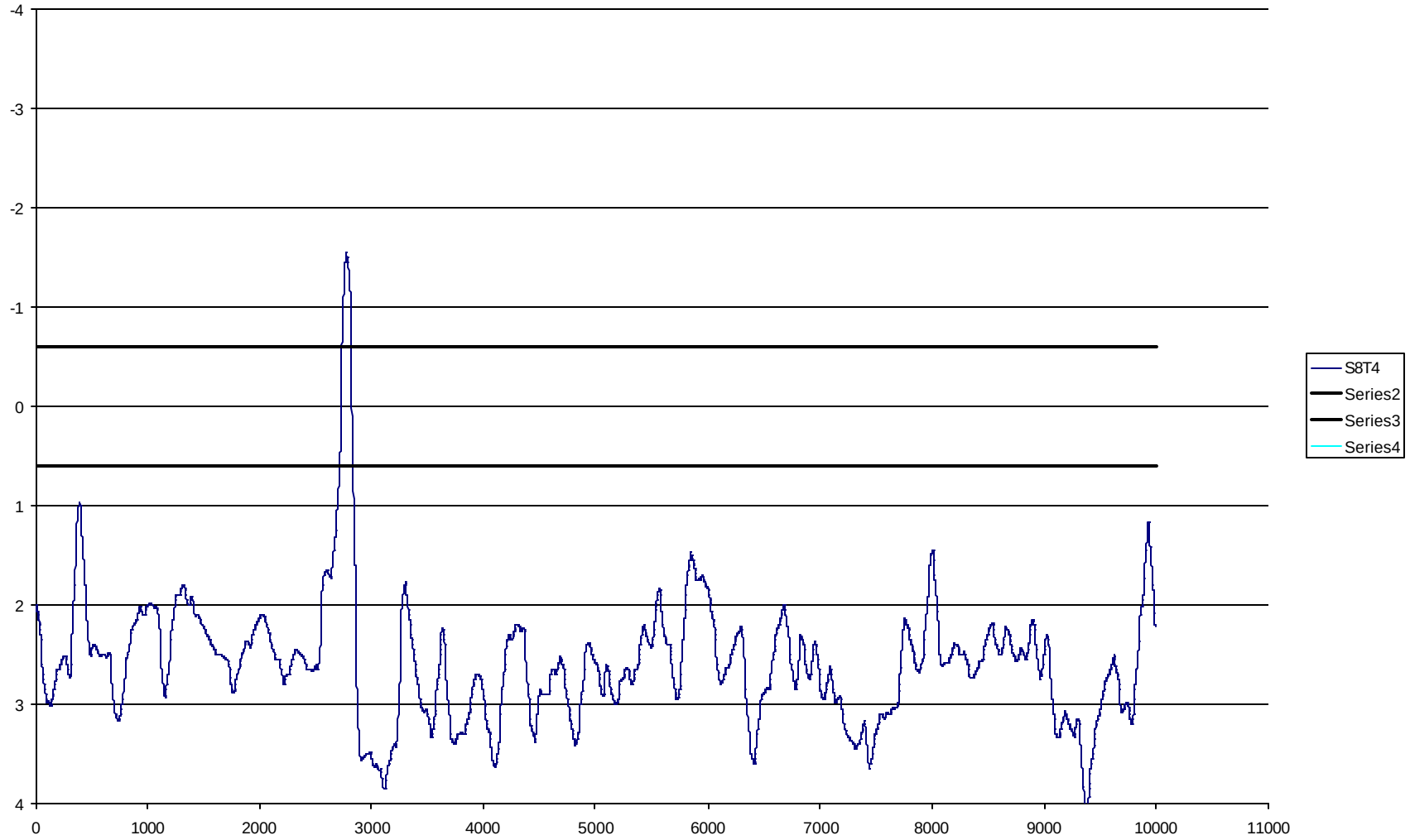

Figure A47: Lane position (in meters relative to center of road) for S8 driving for 10 km under Condition T4.

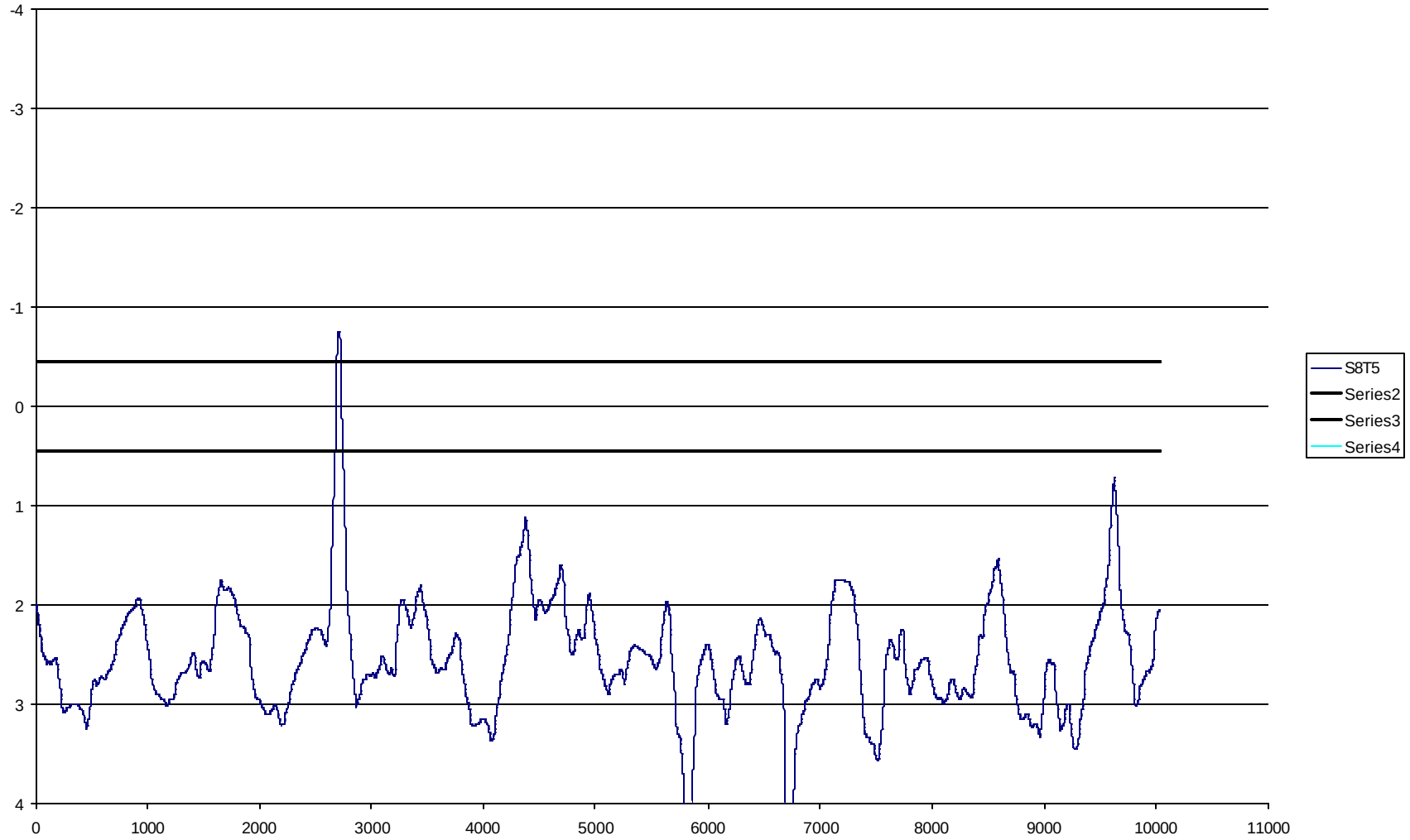

Figure A48: Lane position (in meters relative to center of road) for S8 driving for 10 km under Condition T5.

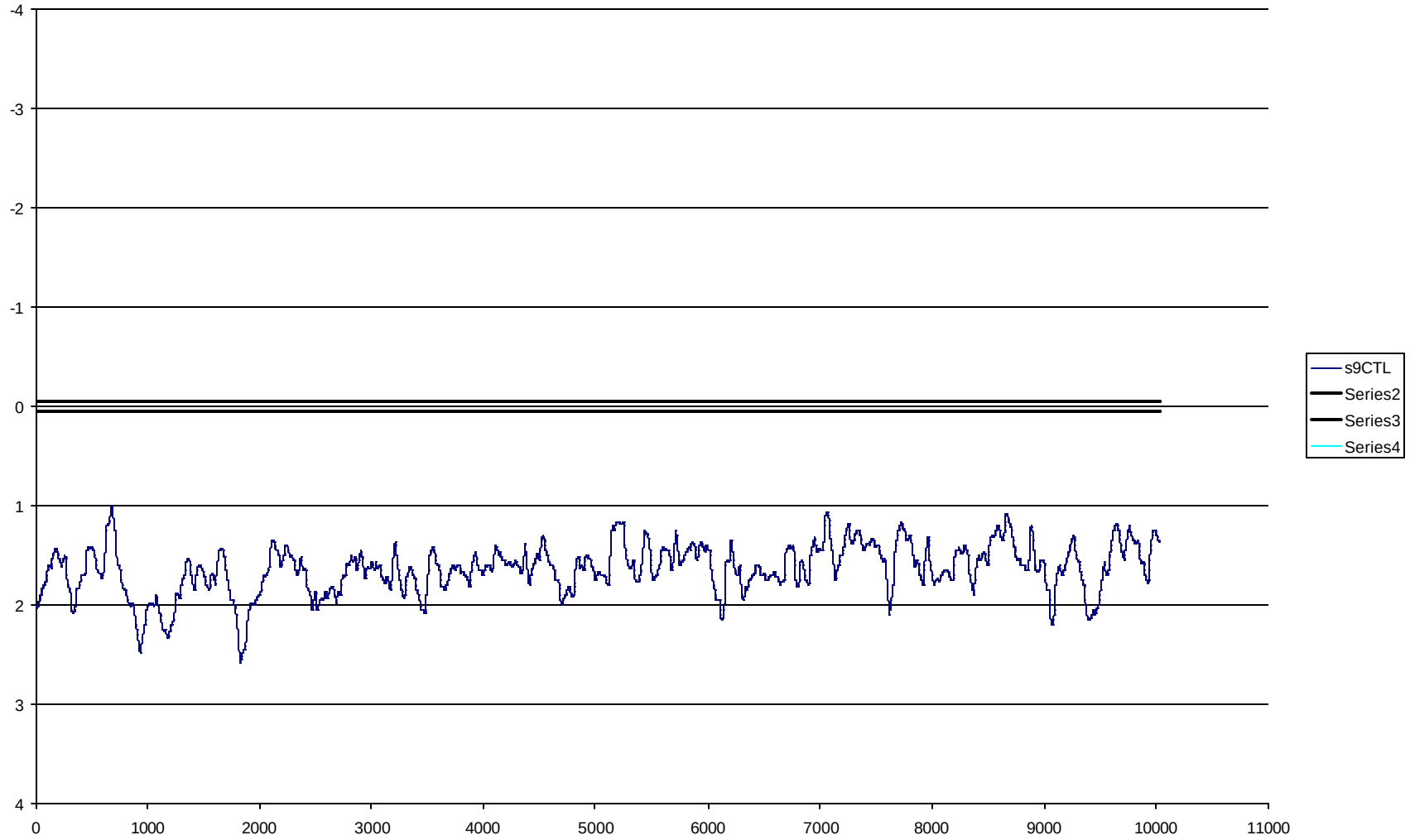

Figure A49: Lane position (in meters relative to center of road) for S9 driving for 10 km under Condition CTL.

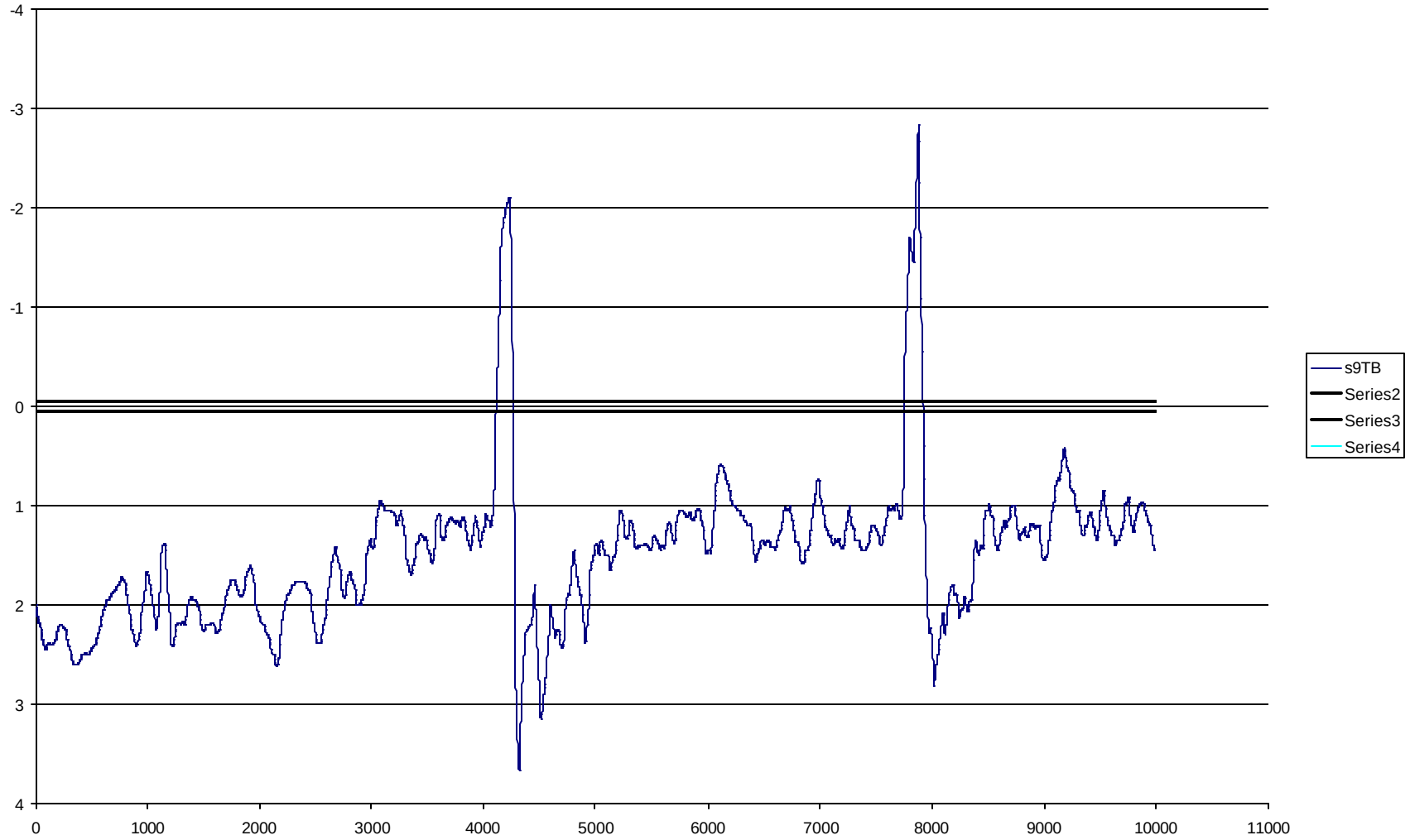

Figure A50: Lane position (in meters relative to center of road) for S9 driving for 10 km under Condition TB.

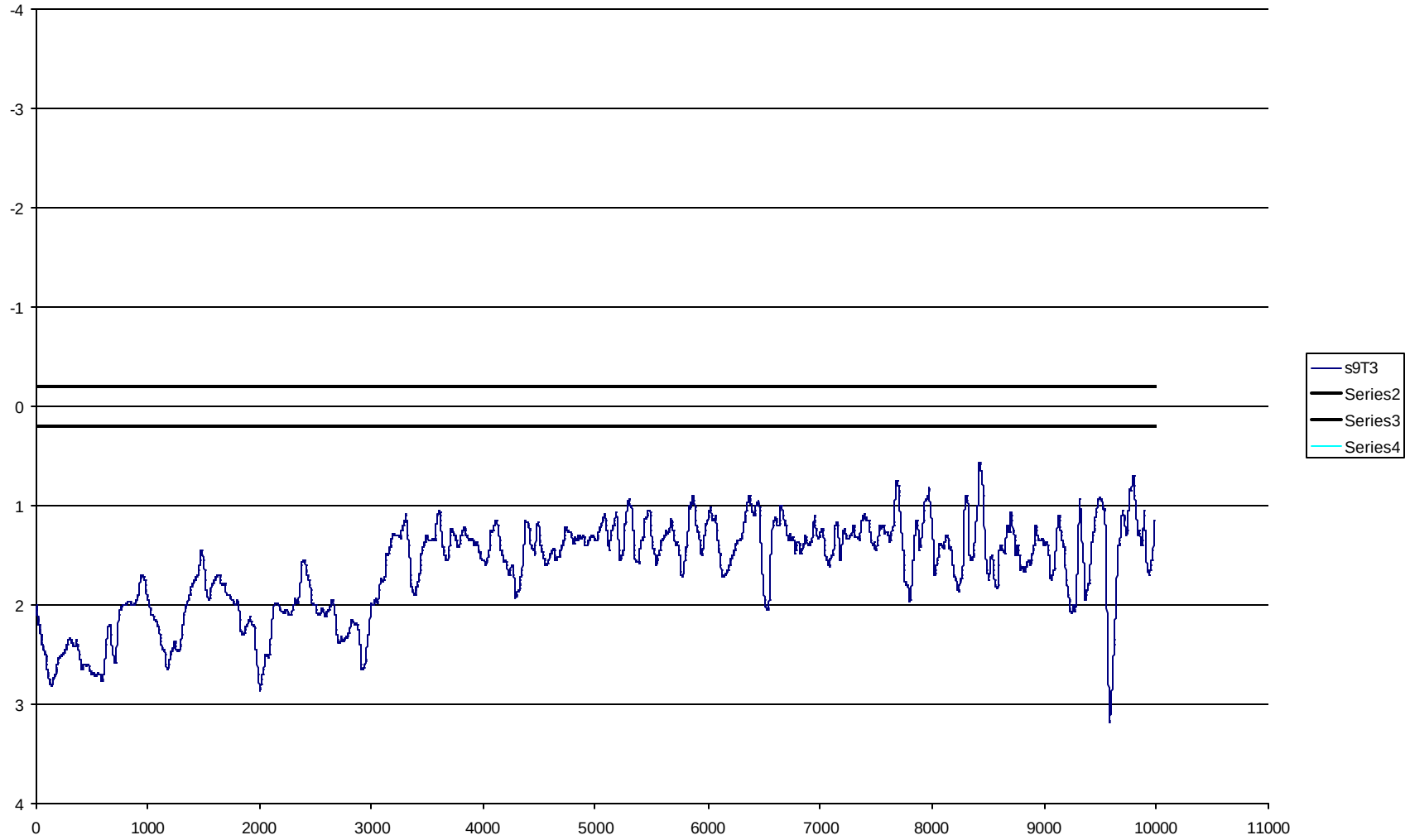

Figure A51: Lane position (in meters relative to center of road) for S9 driving for 10 km under Condition T3.

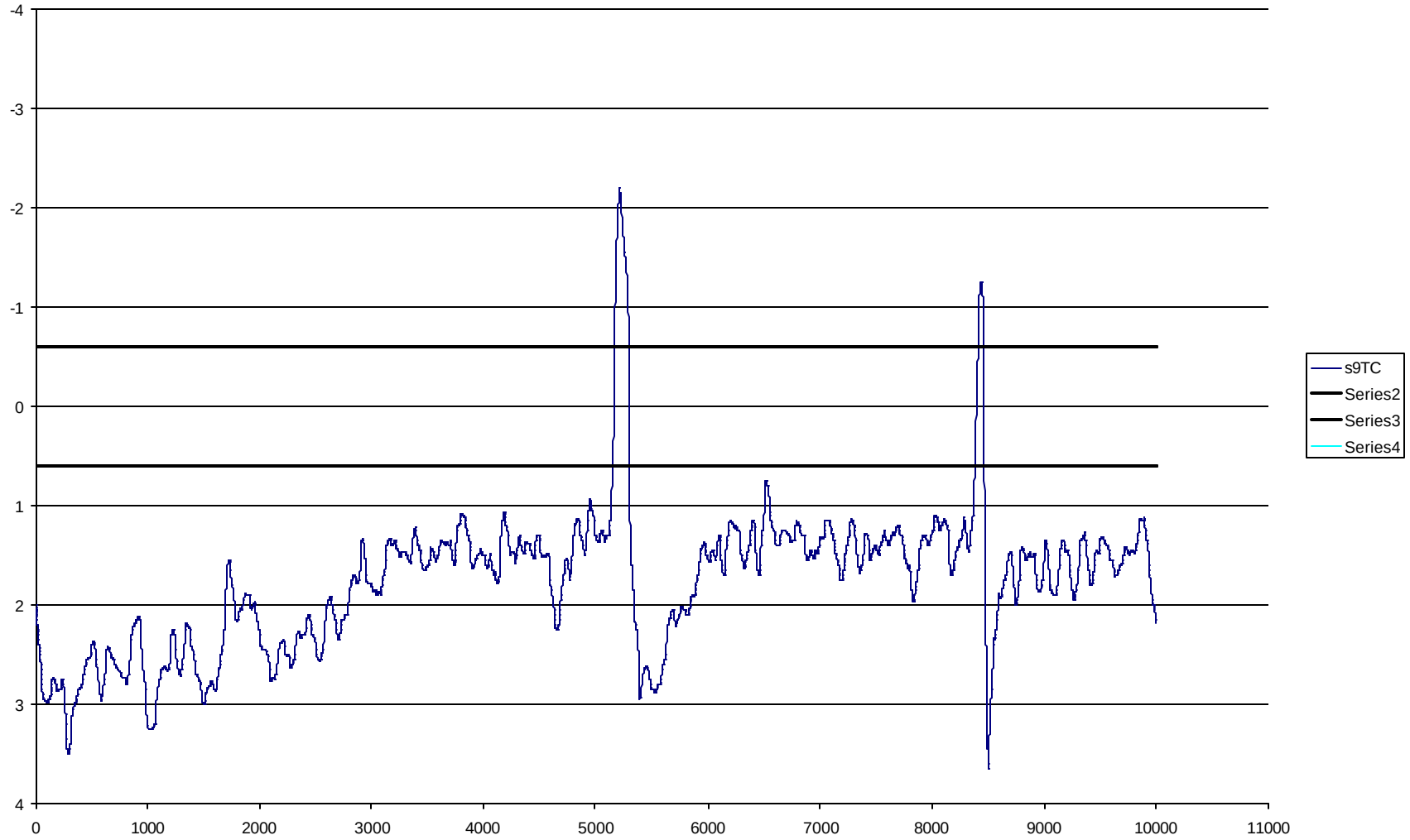

Figure A52: Lane position (in meters relative to center of road) for S9 driving for 10 km under Condition TC.

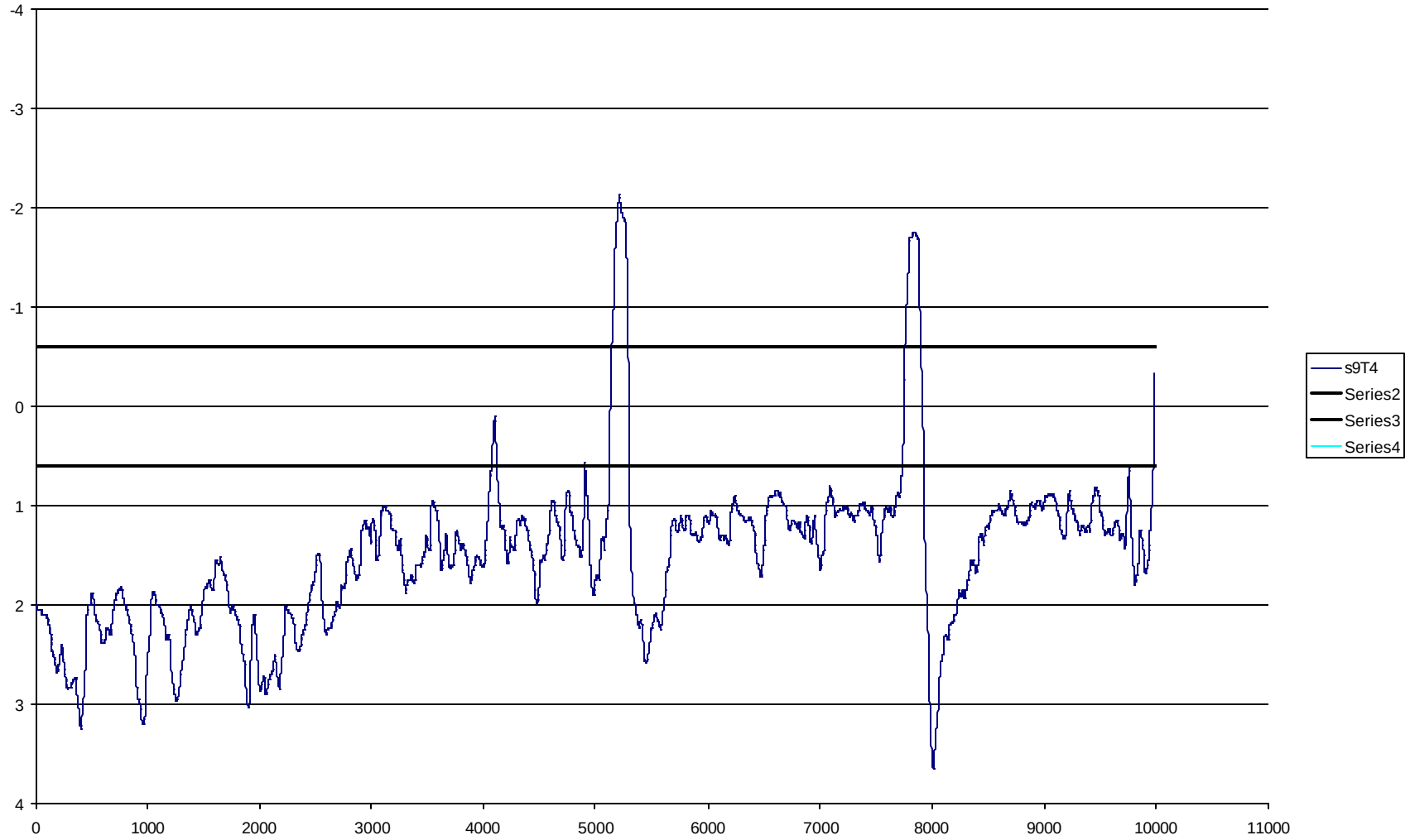

Figure A53: Lane position (in meters relative to center of road) for S9 driving for 10 km under Condition T4.

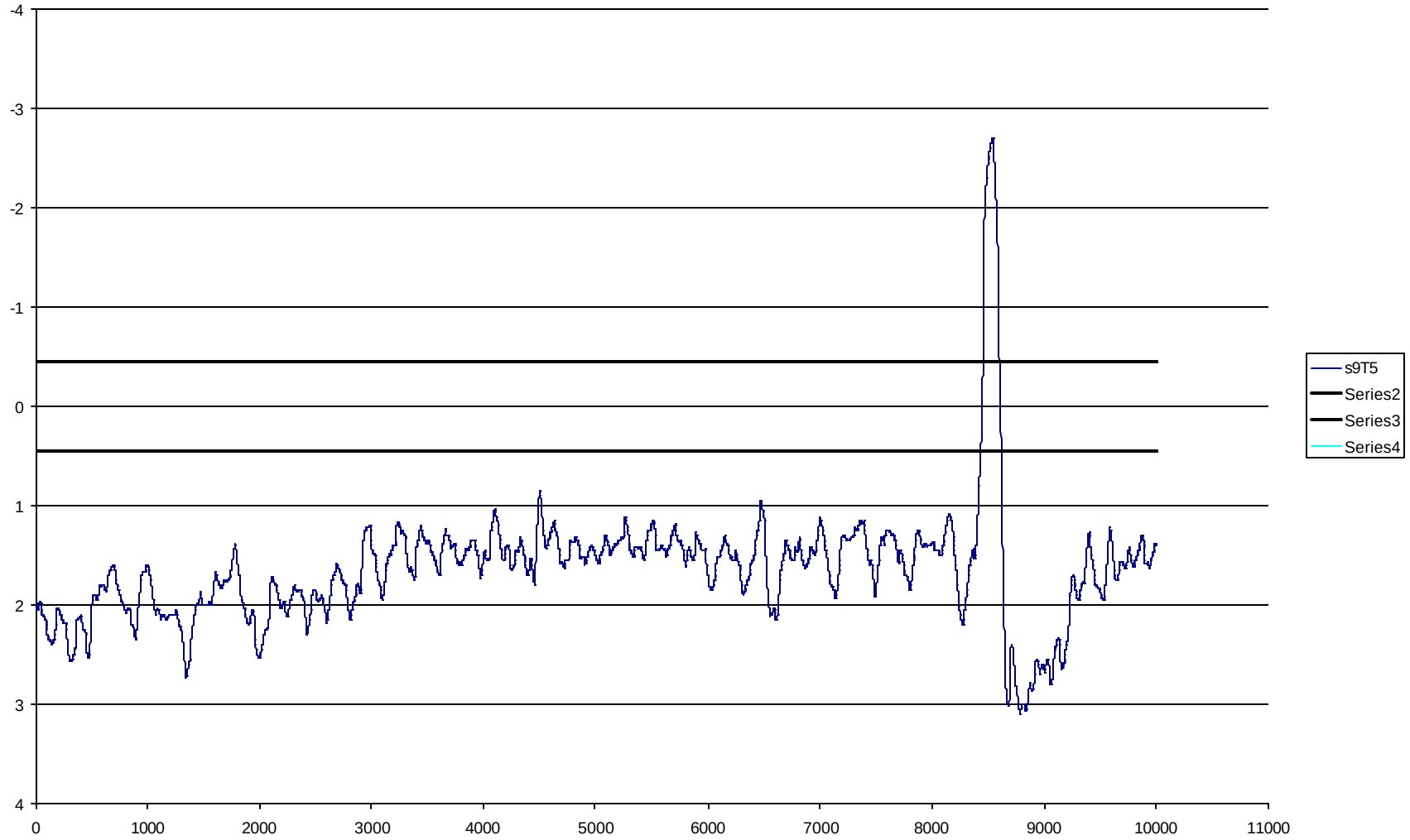

Figure A54: Lane position (in meters relative to center of road) for S9 driving for 10 km under Condition T5.

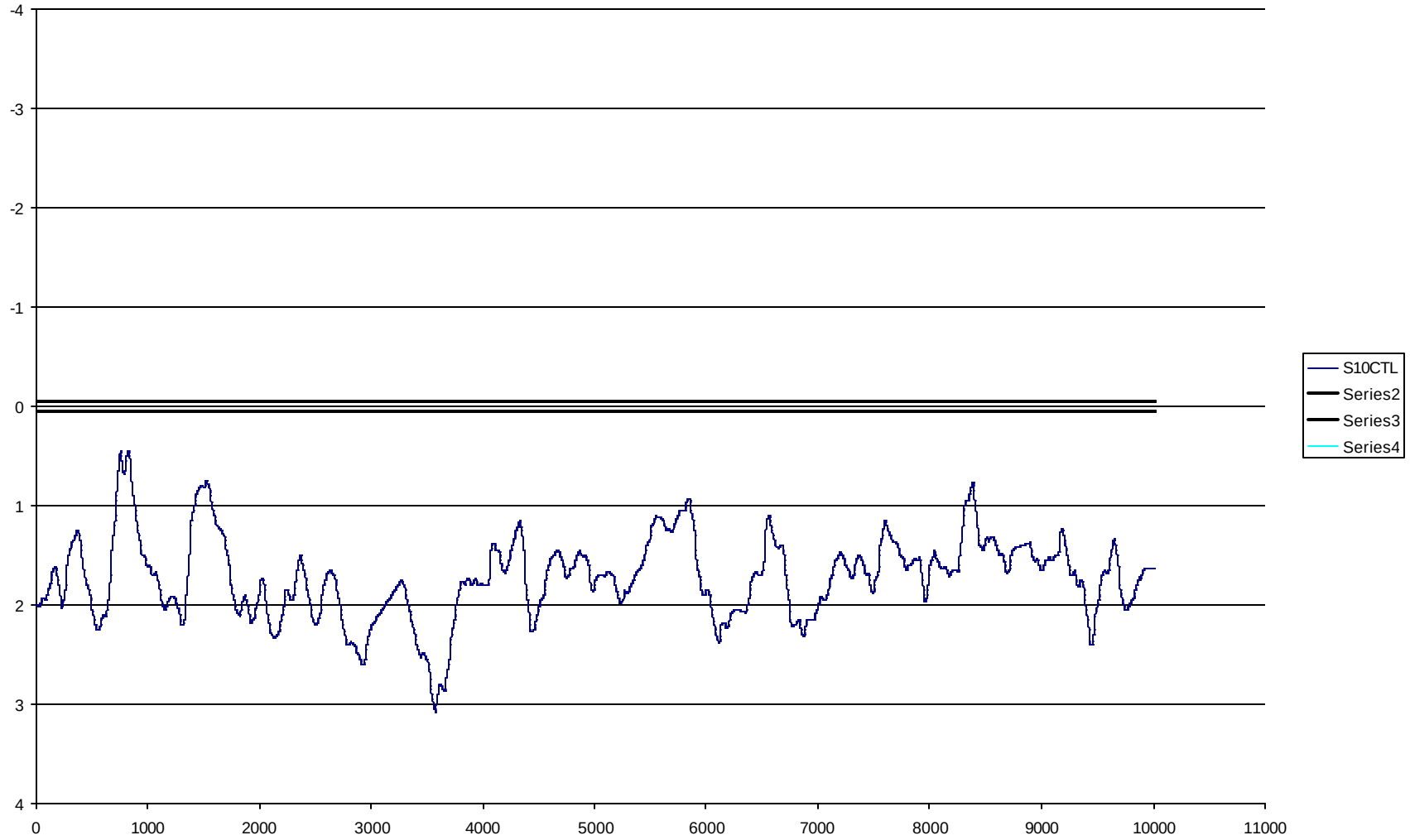

Figure A55: Lane position (in meters relative to center of road) for S10 driving for 10 km under Condition CTL.

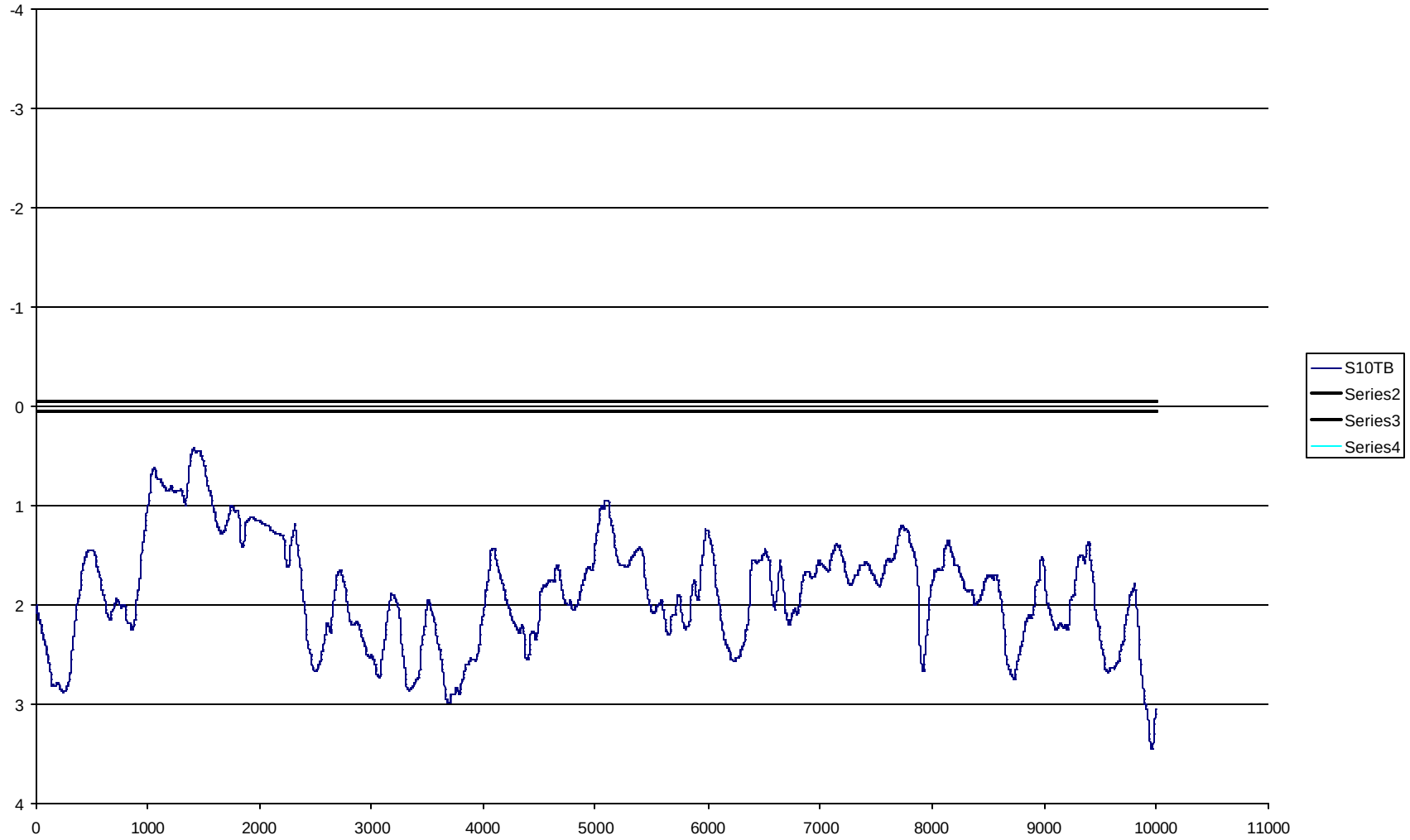

Figure A56: Lane position (in meters relative to center of road) for S10 driving for 10 km under Condition TB.

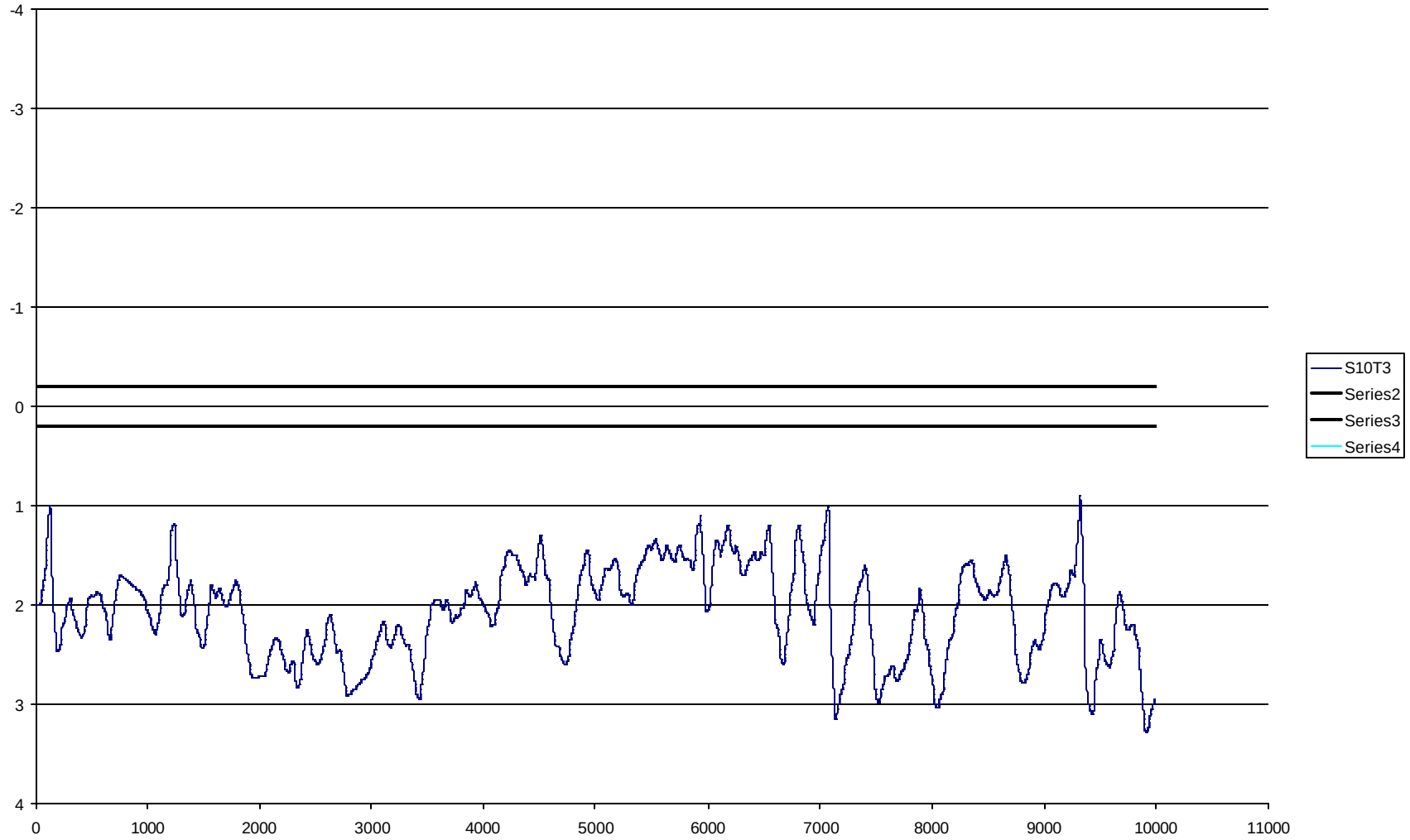

Figure A57: Lane position (in meters relative to center of road) for S10 driving for 10 km under Condition T3.

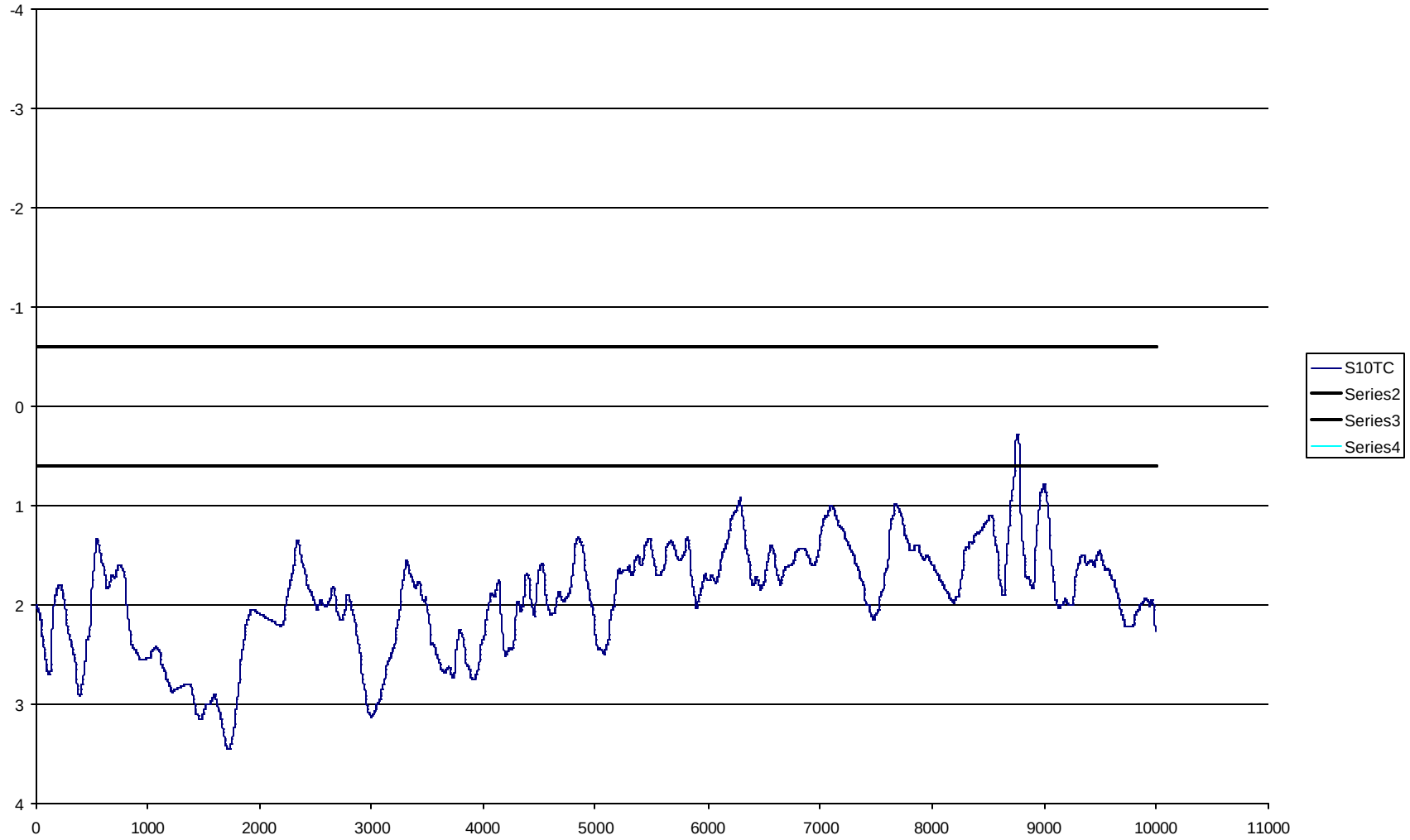

Figure A58: Lane position (in meters relative to center of road) for S10 driving for 10 km under Condition TC.

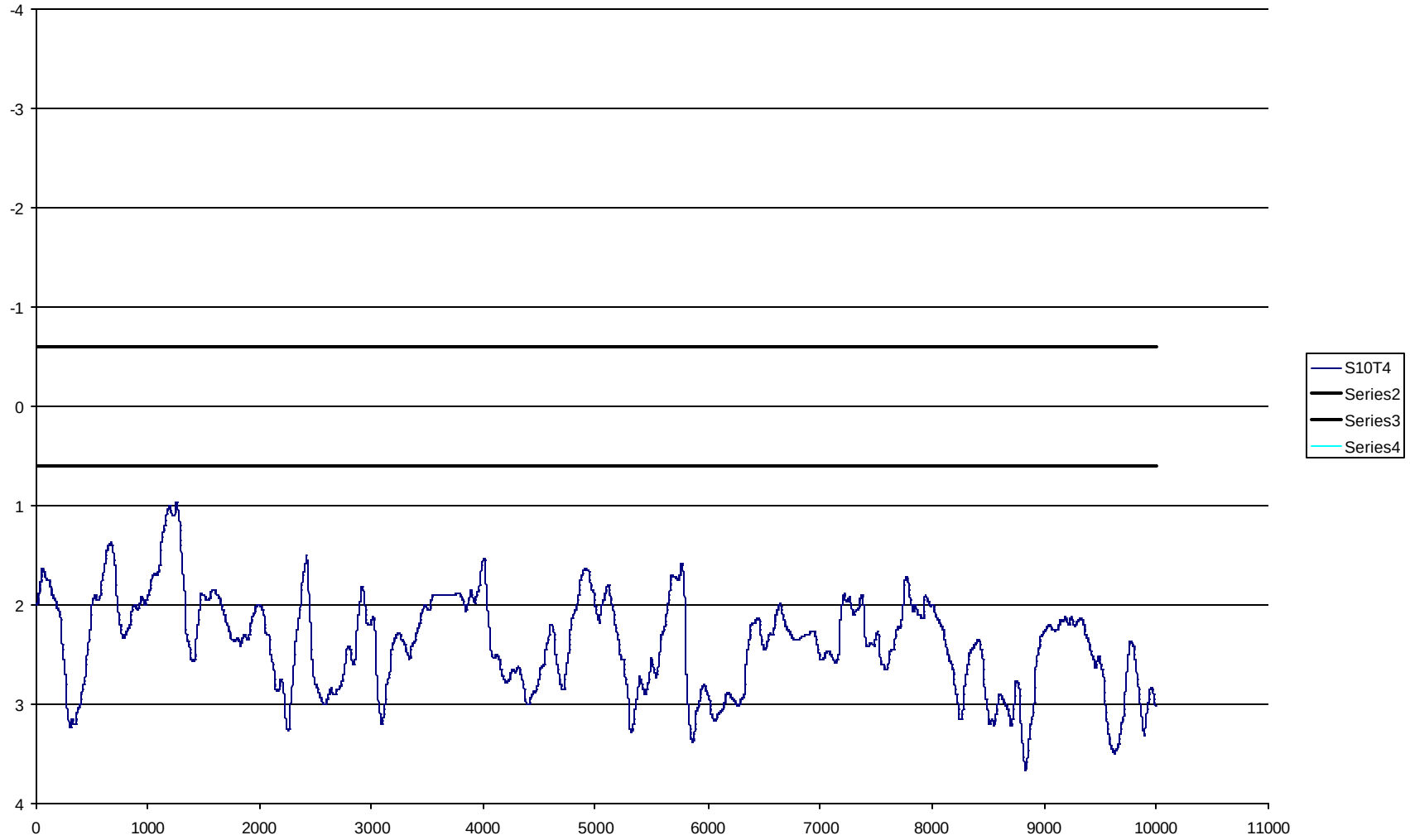

Figure A59: Lane position (in meters relative to center of road) for S10 driving for 10 km under Condition T4.

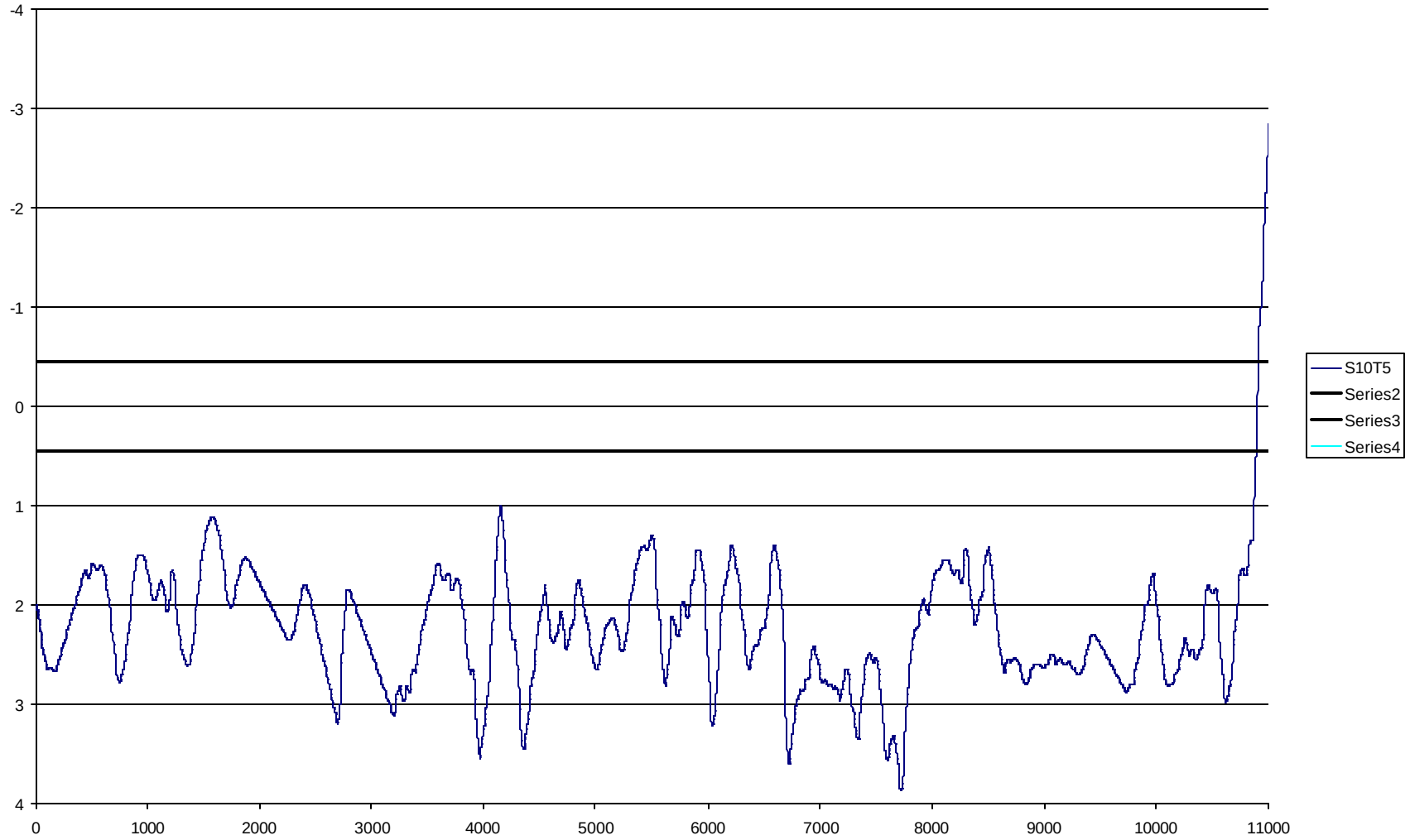

Figure A60: Lane position (in meters relative to center of road) for S10 driving for 10 km under Condition T5.

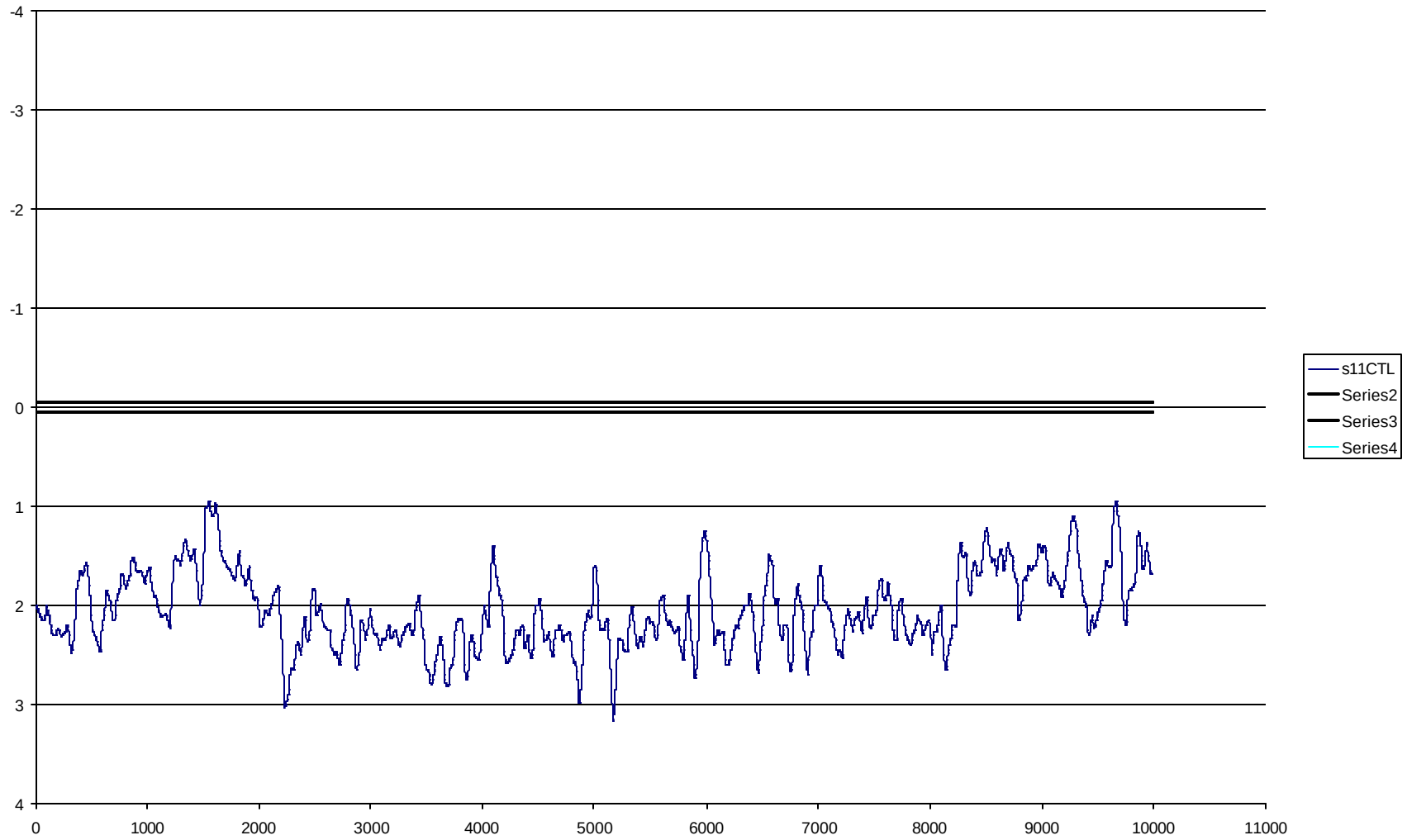

Figure A61: Lane position (in meters relative to center of road) for S11 driving for 10 km under Condition CTL.

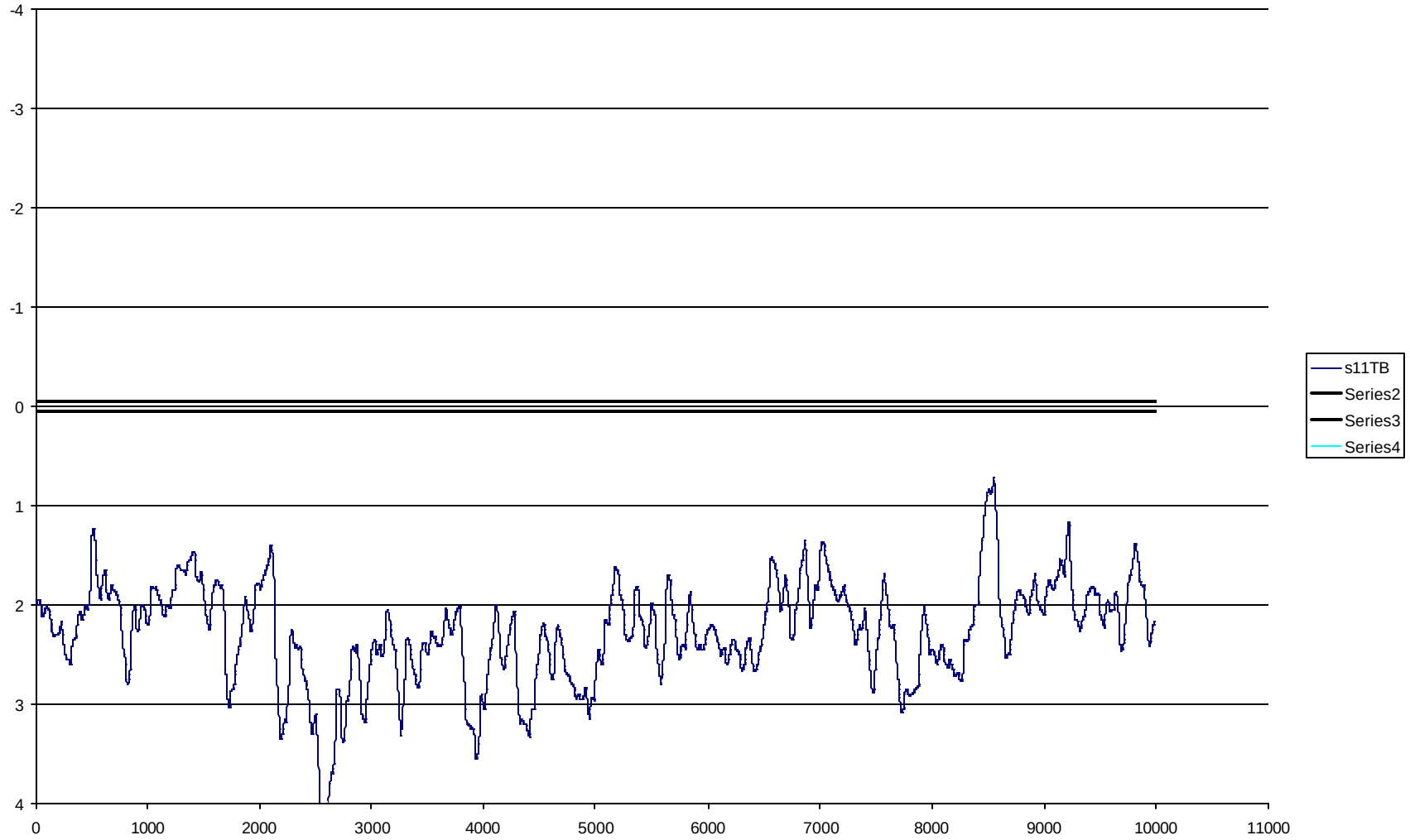

Figure A62: Lane position (in meters relative to center of road) for S11 driving for 10 km under Condition TB.

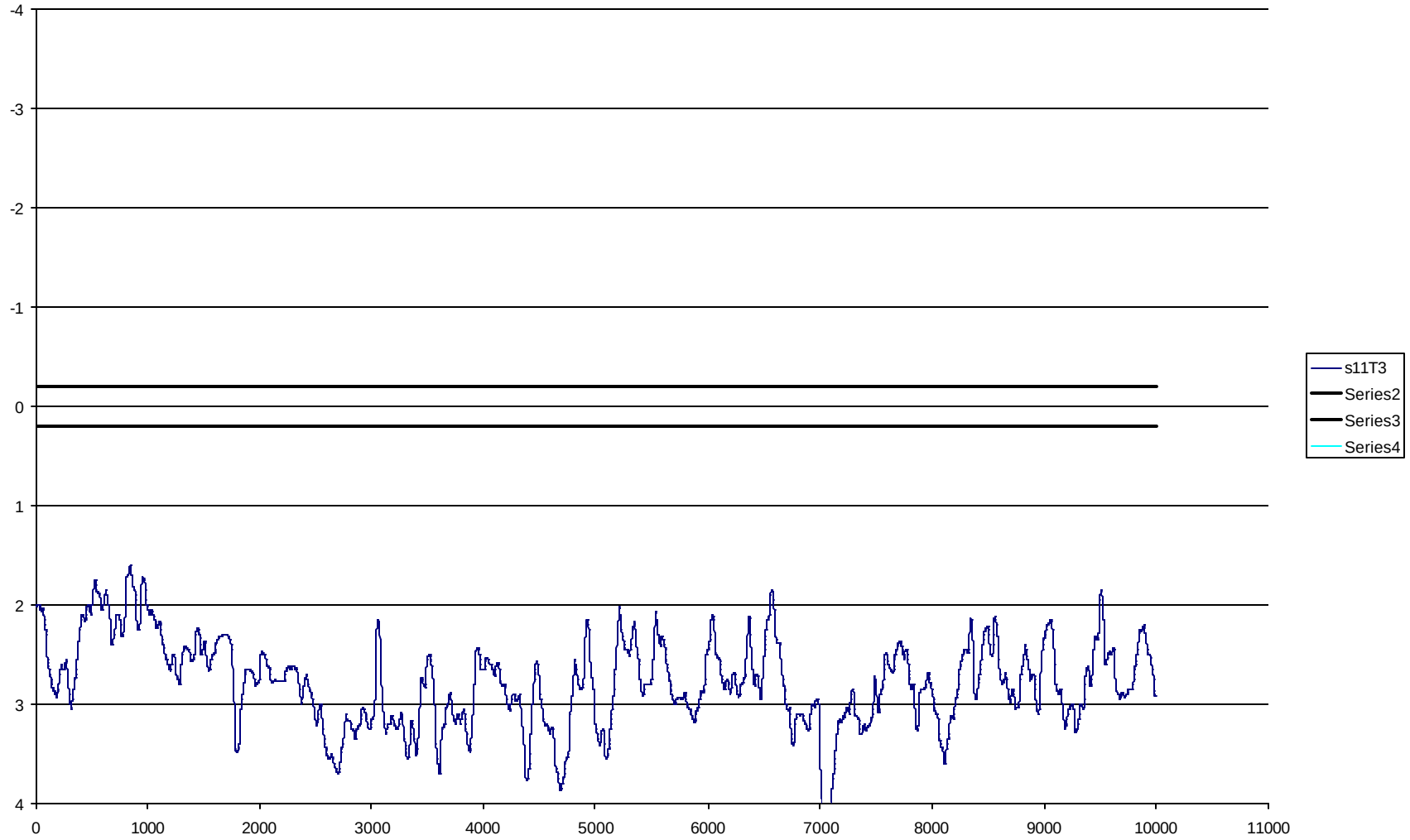

Figure A63: Lane position (in meters relative to center of road) for S11 driving for 10 km under Condition T3.

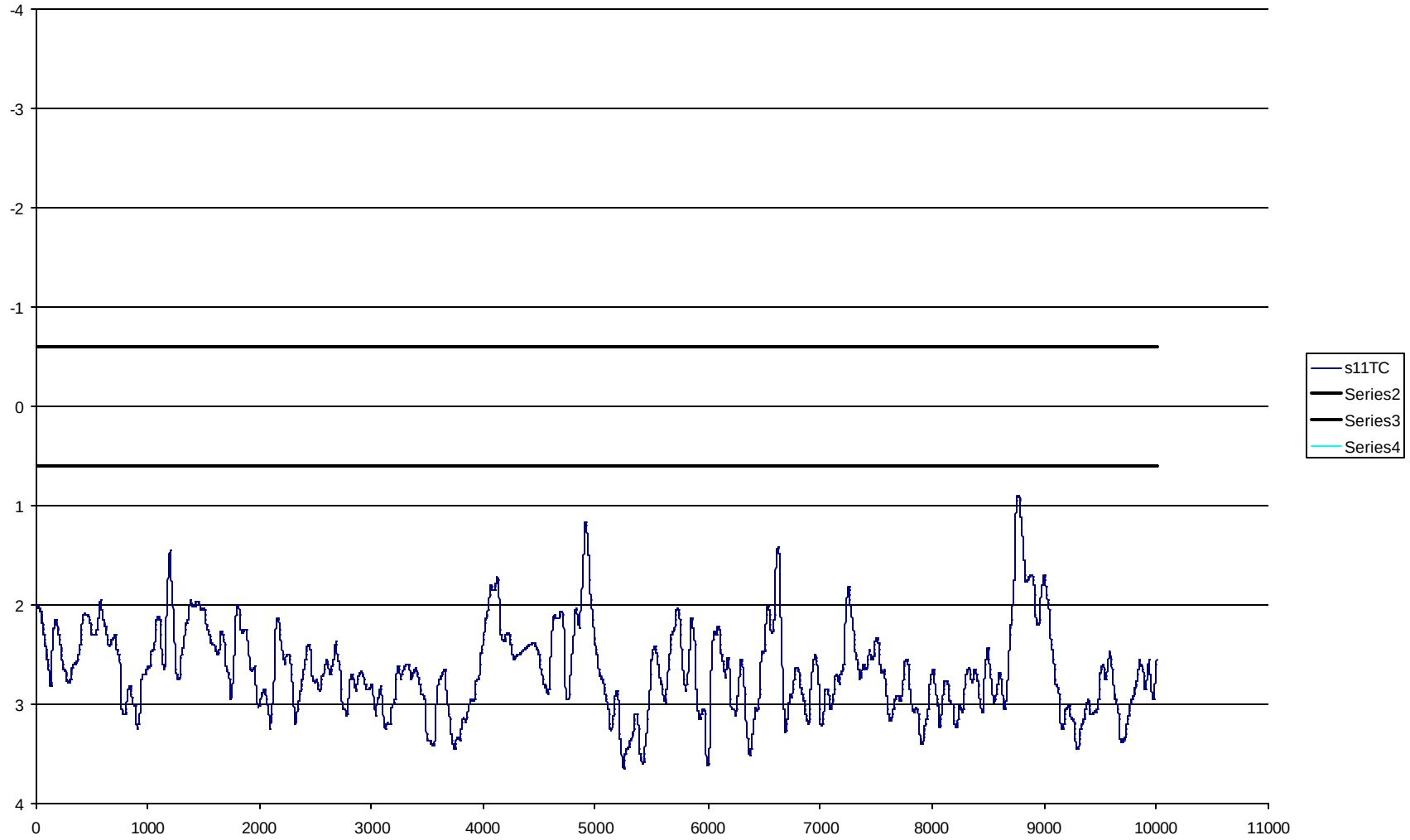

Figure A64: Lane position (in meters relative to center of road) for S11 driving for 10 km under Condition TC.

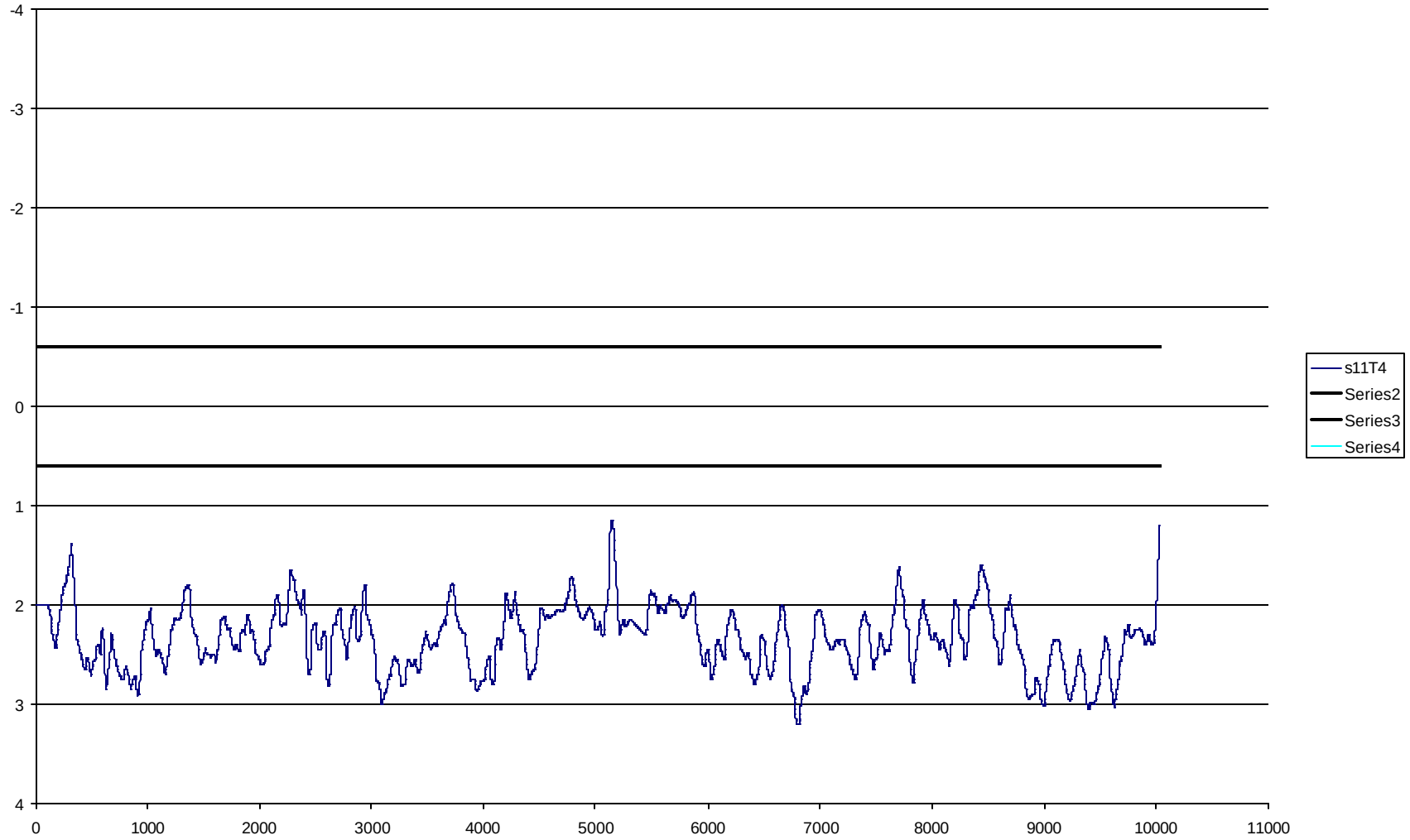

Figure A65: Lane position (in meters relative to center of road) for S11 driving for 10 km under Condition T4.

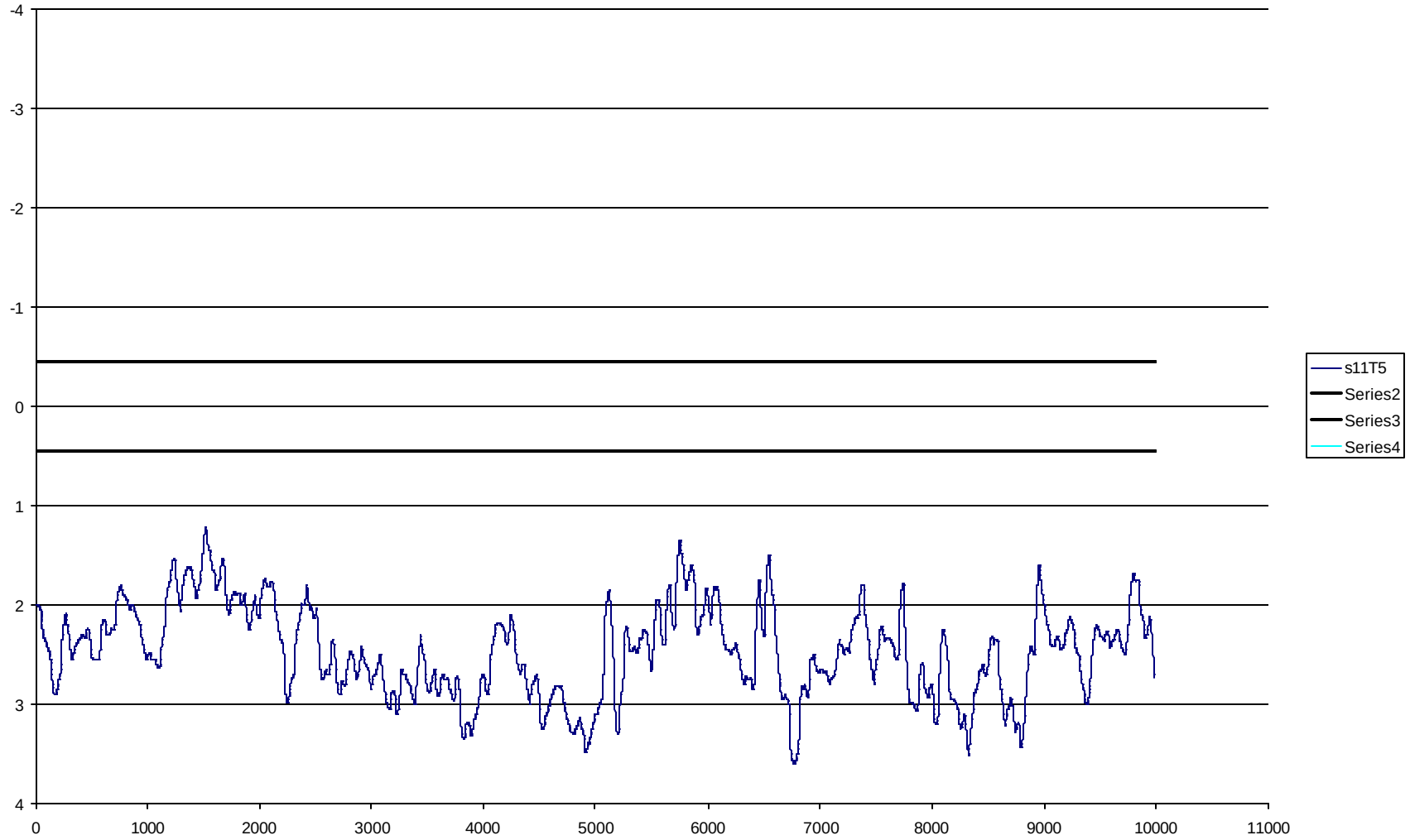

Figure A66: Lane position (in meters relative to center of road) for S11 driving for 10 km under Condition T5.

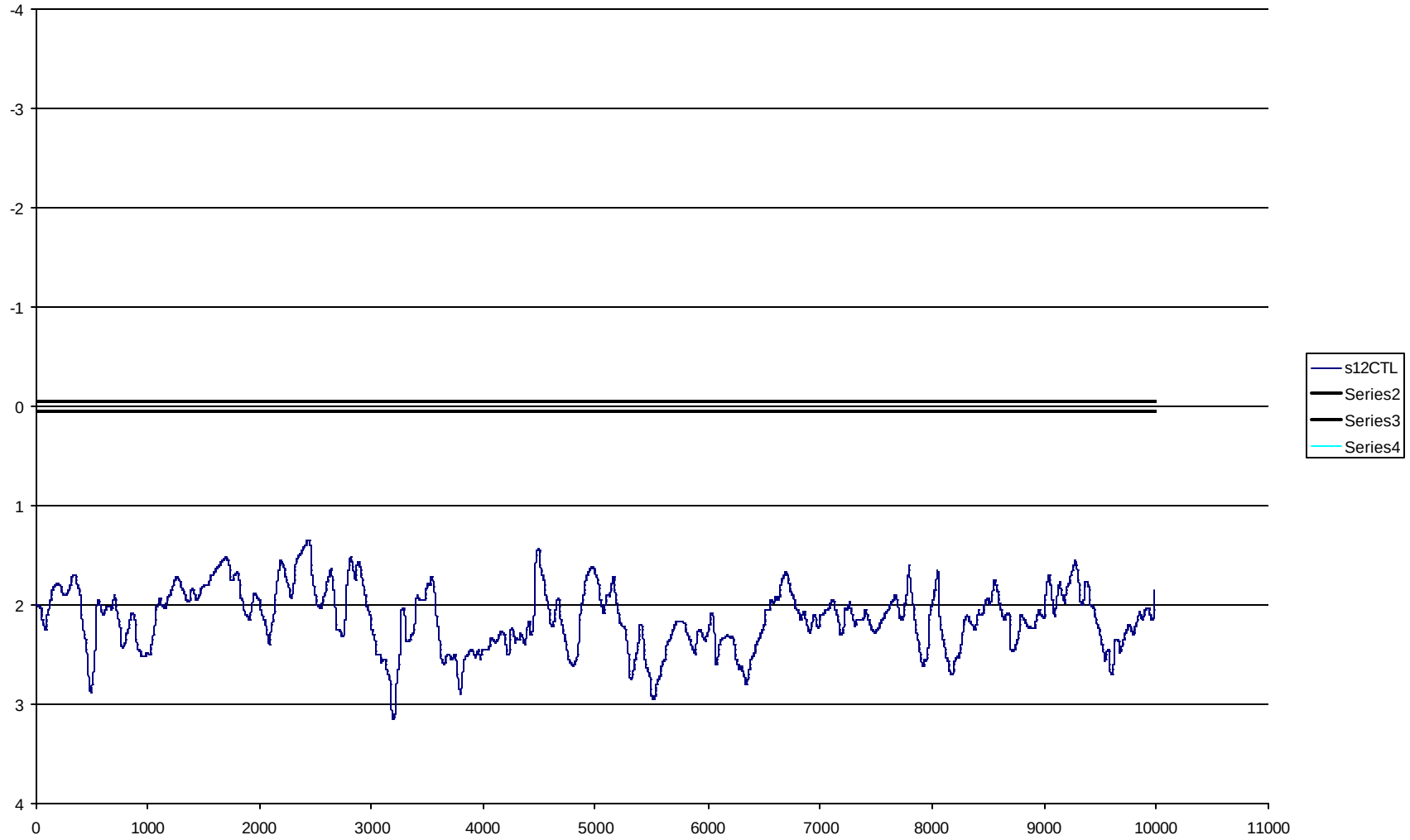

Figure A67: Lane position (in meters relative to center of road) for S12 driving for 10 km under Condition CTL.

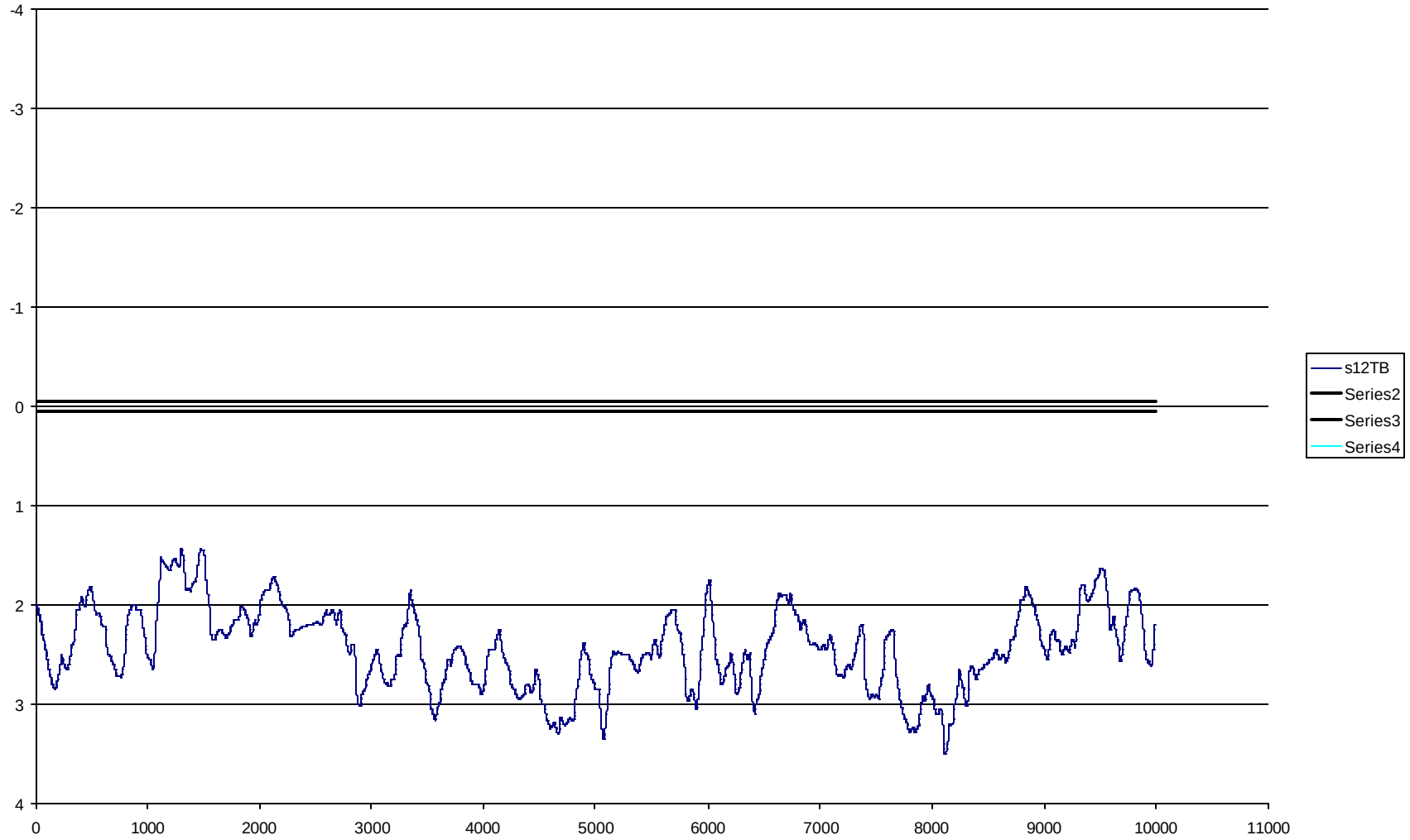

Figure A68: Lane position (in meters relative to center of road) for S12 driving for 10 km under Condition TB.

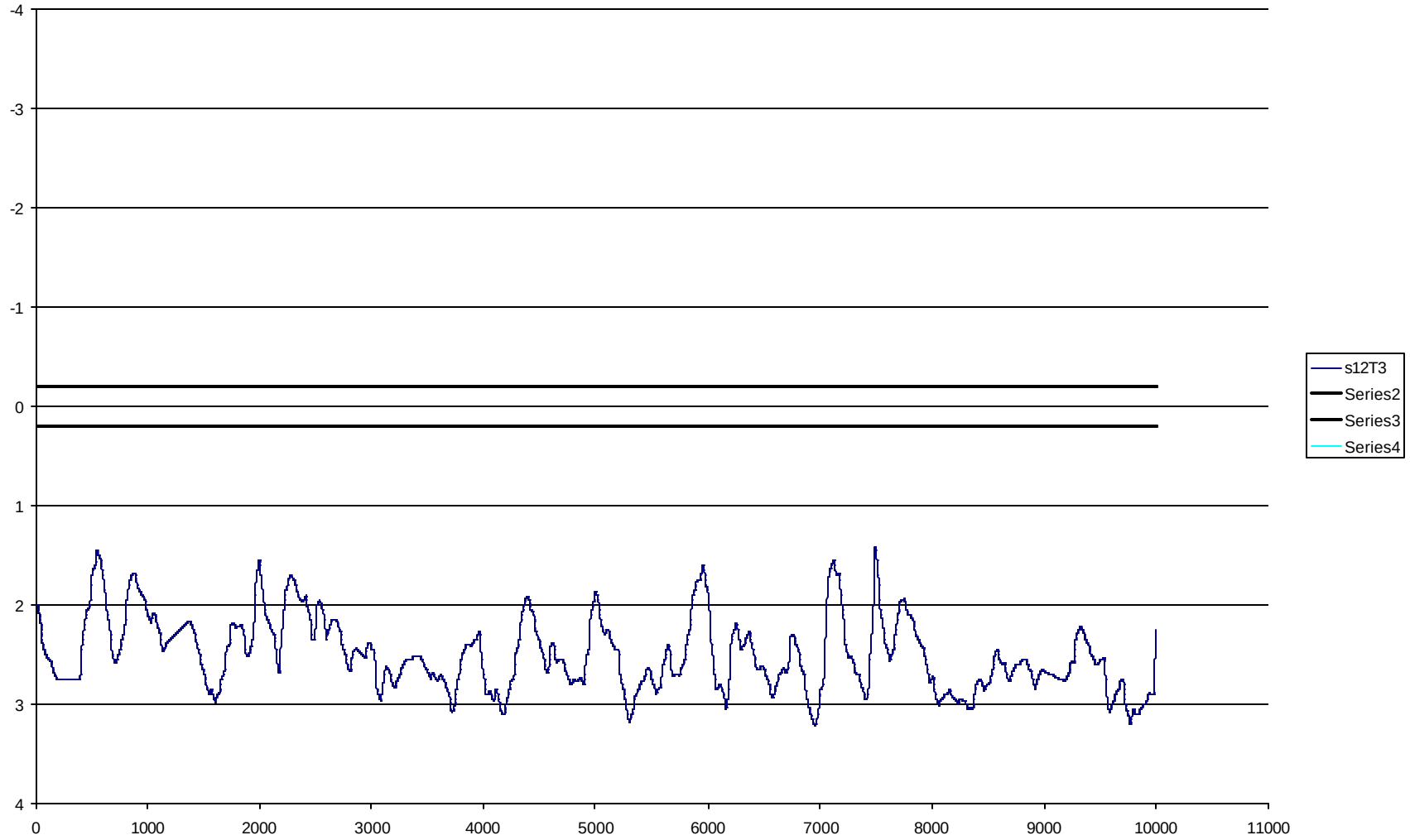

Figure A69: Lane position (in meters relative to center of road) for S12 driving for 10 km under Condition T3.

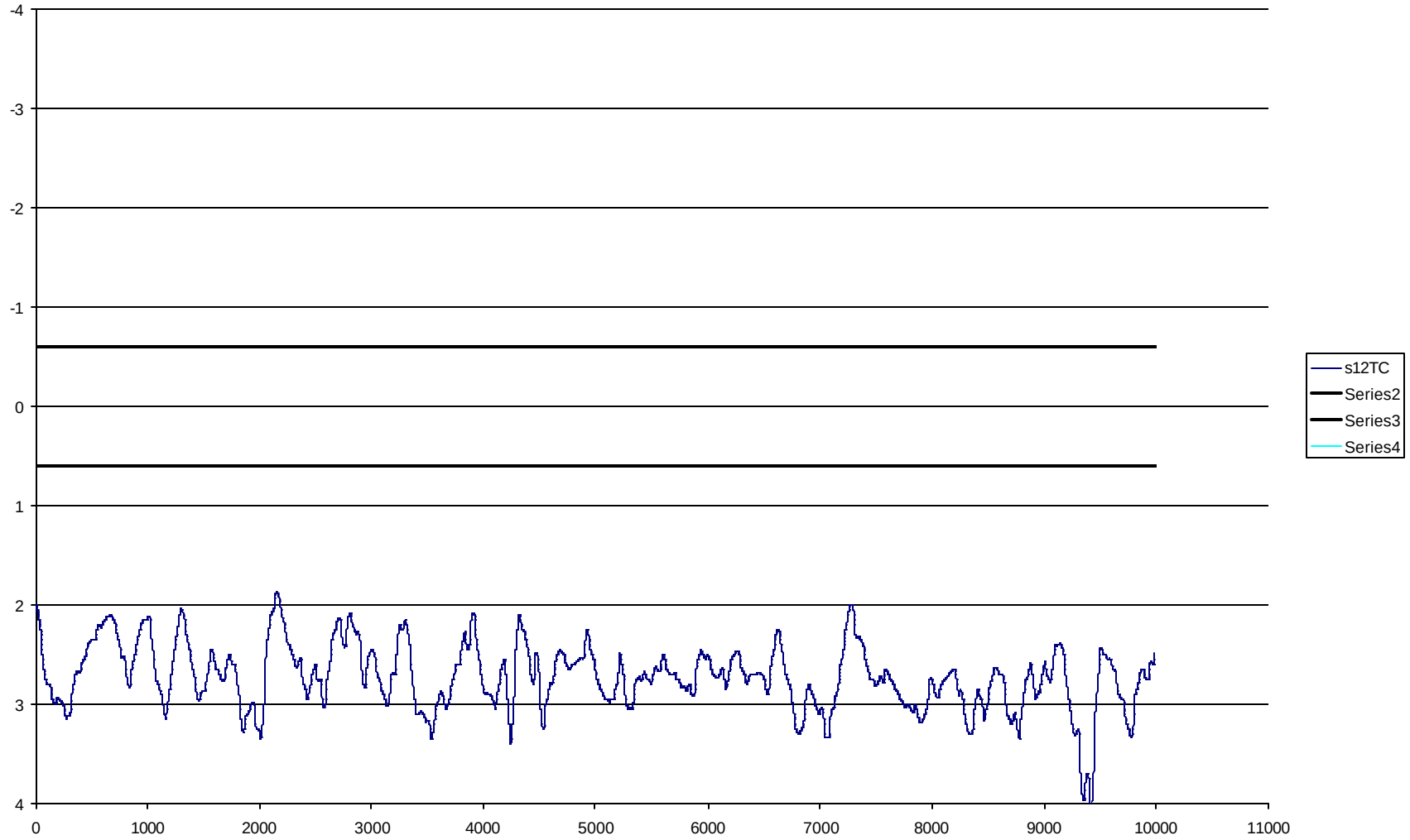

Figure A70: Lane position (in meters relative to center of road) for S12 driving for 10 km under Condition TC.

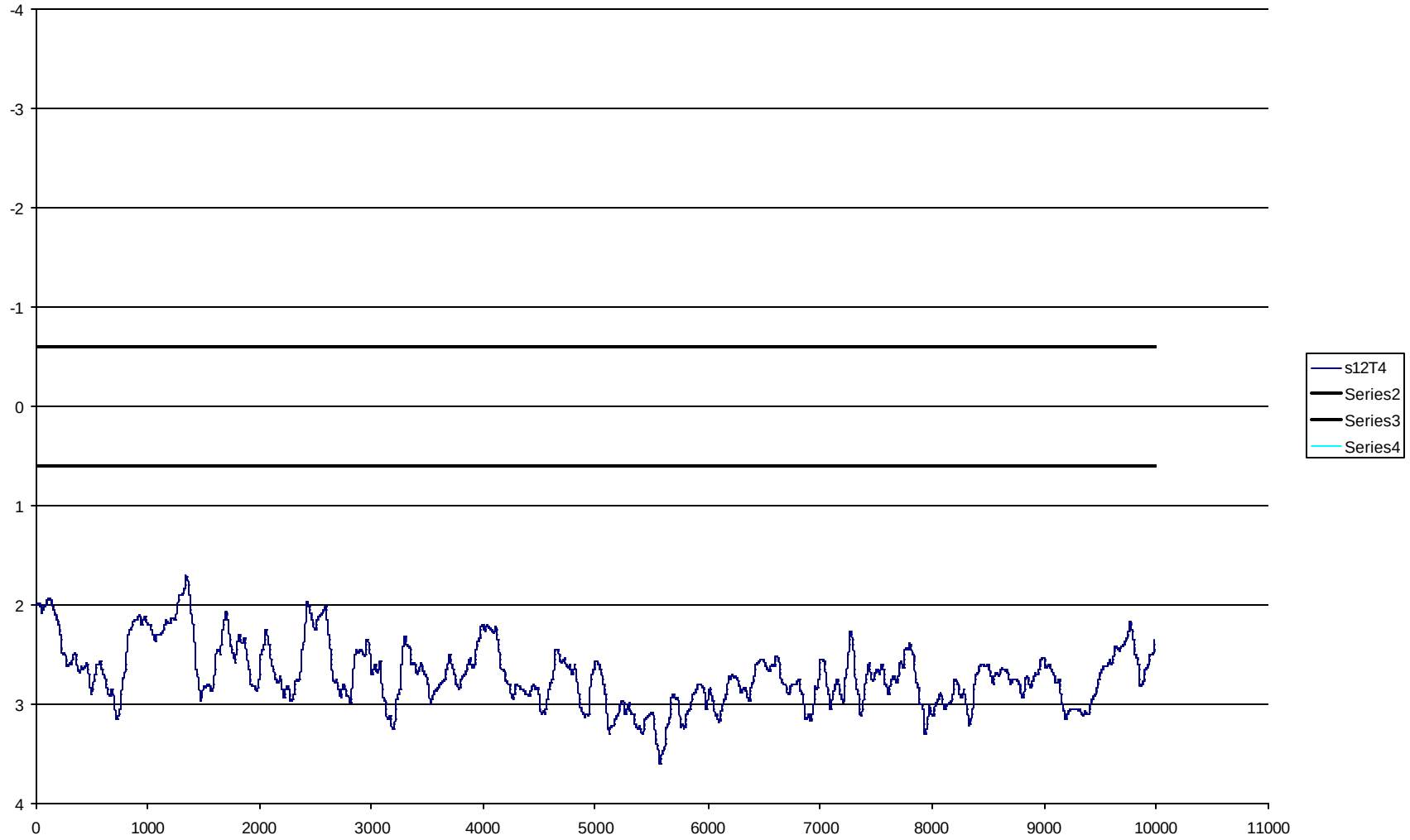

Figure A71: Lane position (in meters relative to center of road) for S12 driving for 10 km under Condition T4.

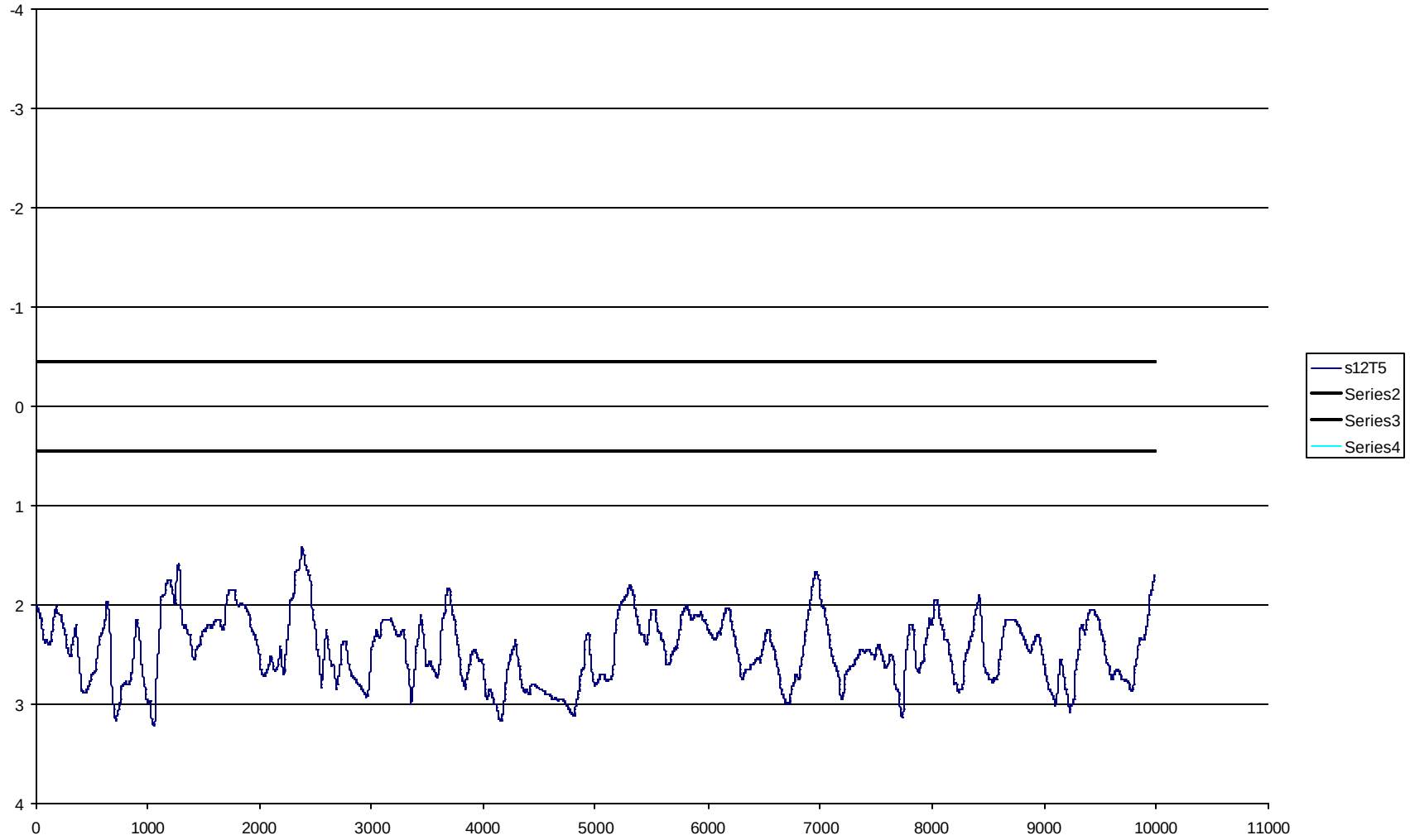

Figure A72: Lane position (in meters relative to center of road) for S12 driving for 10 km under Condition T5.

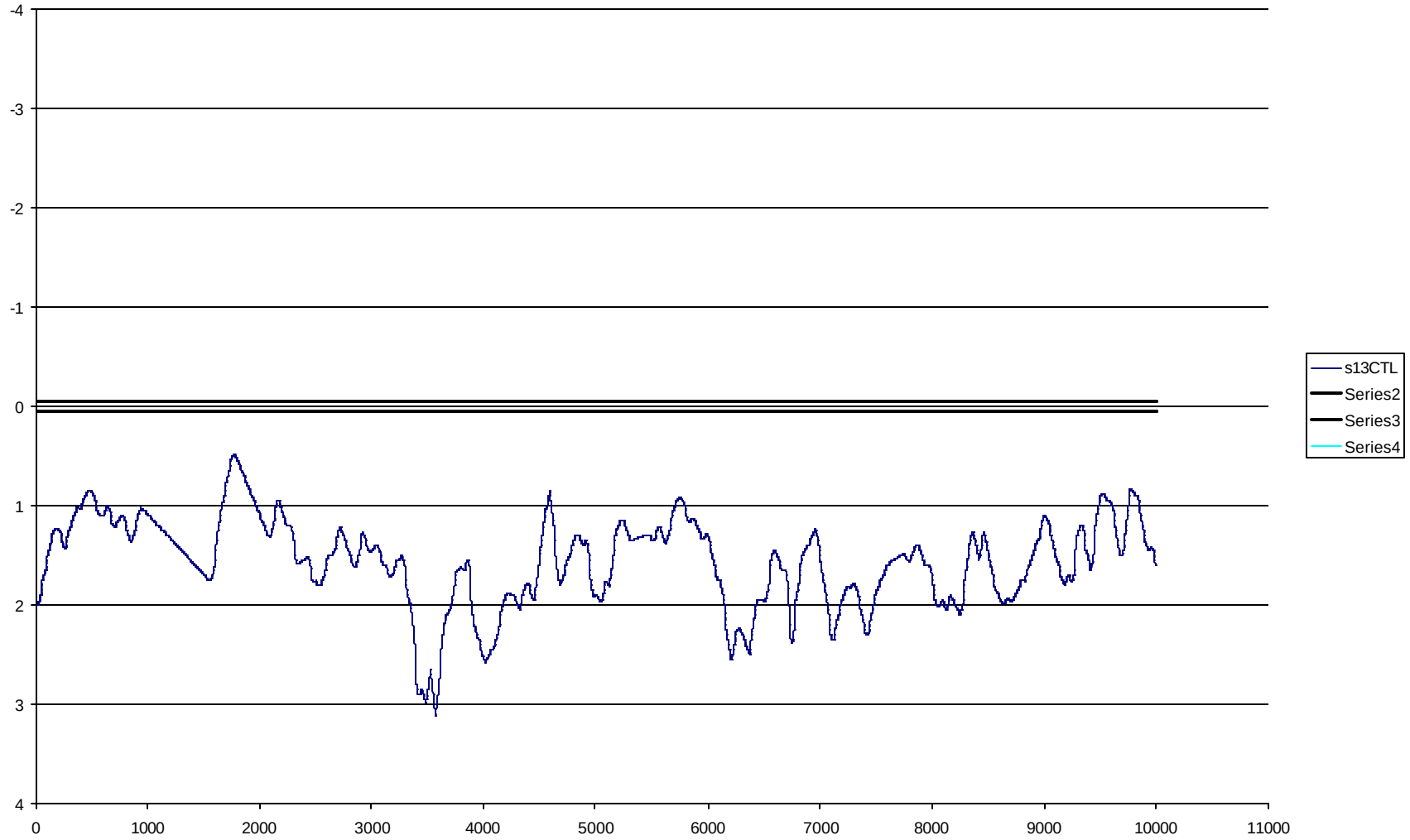

Figure A73: Lane position (in meters relative to center of road) for S13 driving for 10 km under Condition CTL.

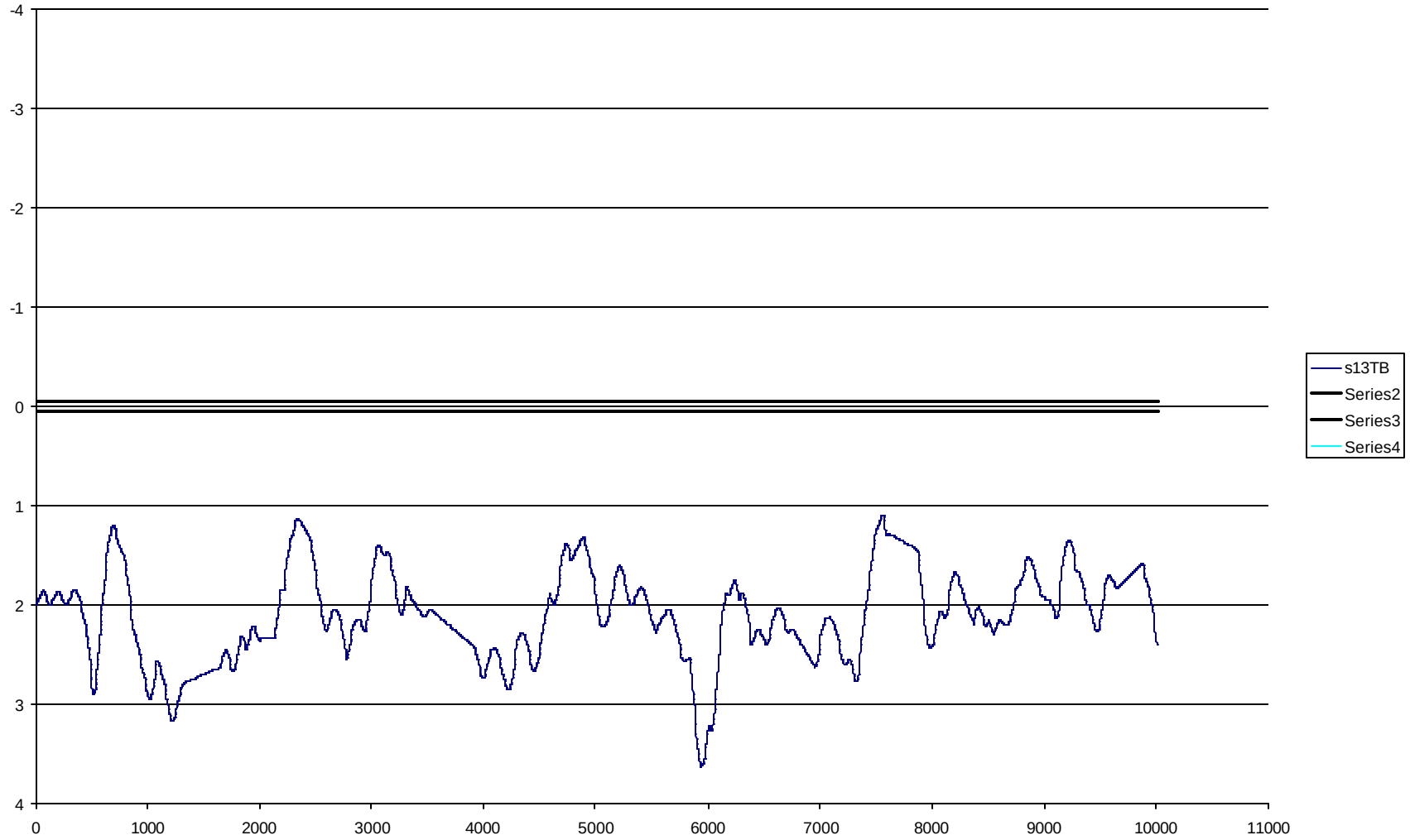

Figure A74: Lane position (in meters relative to center of road) for S13 driving for 10 km under Condition TB.

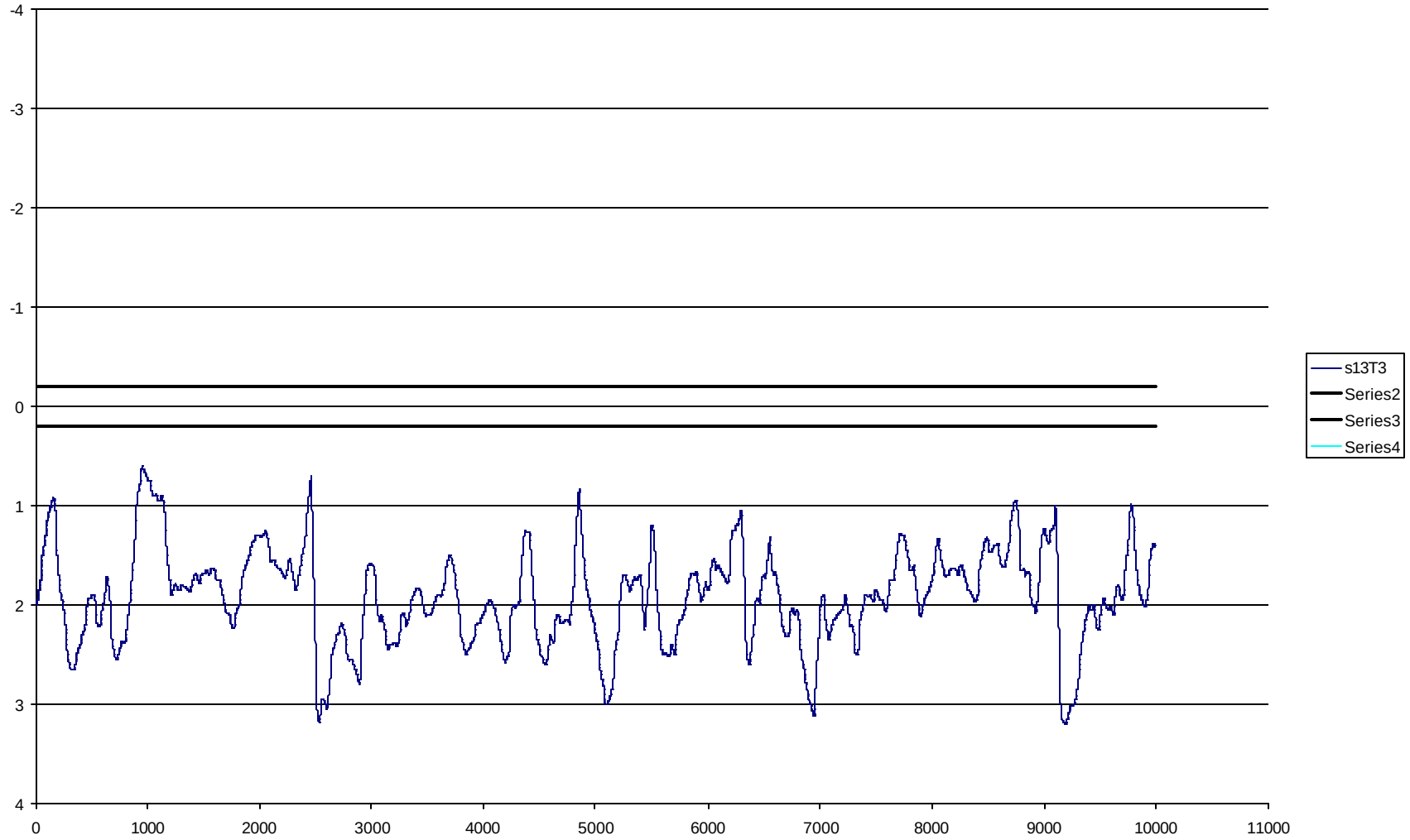

Figure A75: Lane position (in meters relative to center of road) for S13 driving for 10 km under Condition T3.

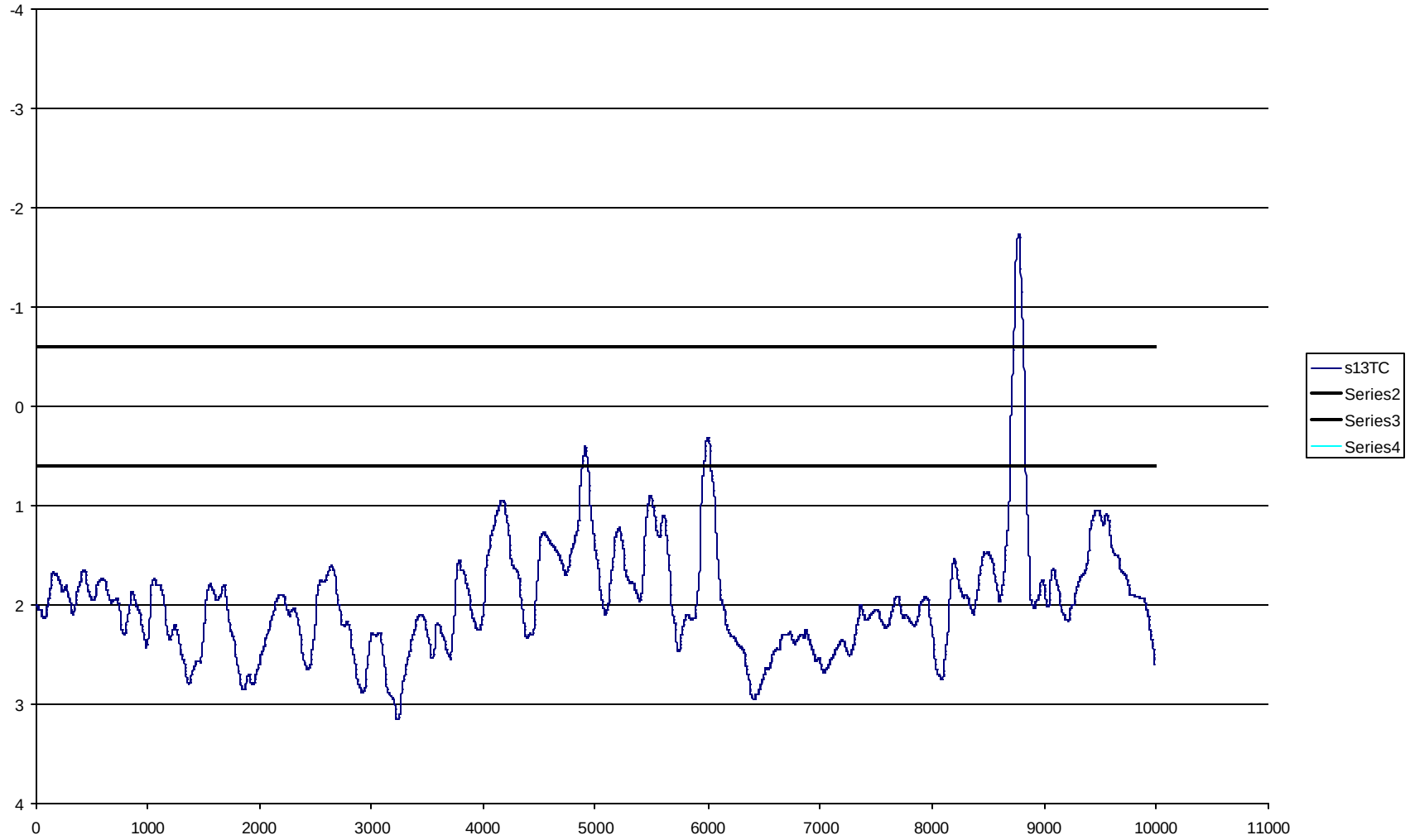

Figure A76: Lane position (in meters relative to center of road) for S13 driving for 10 km under Condition TC.

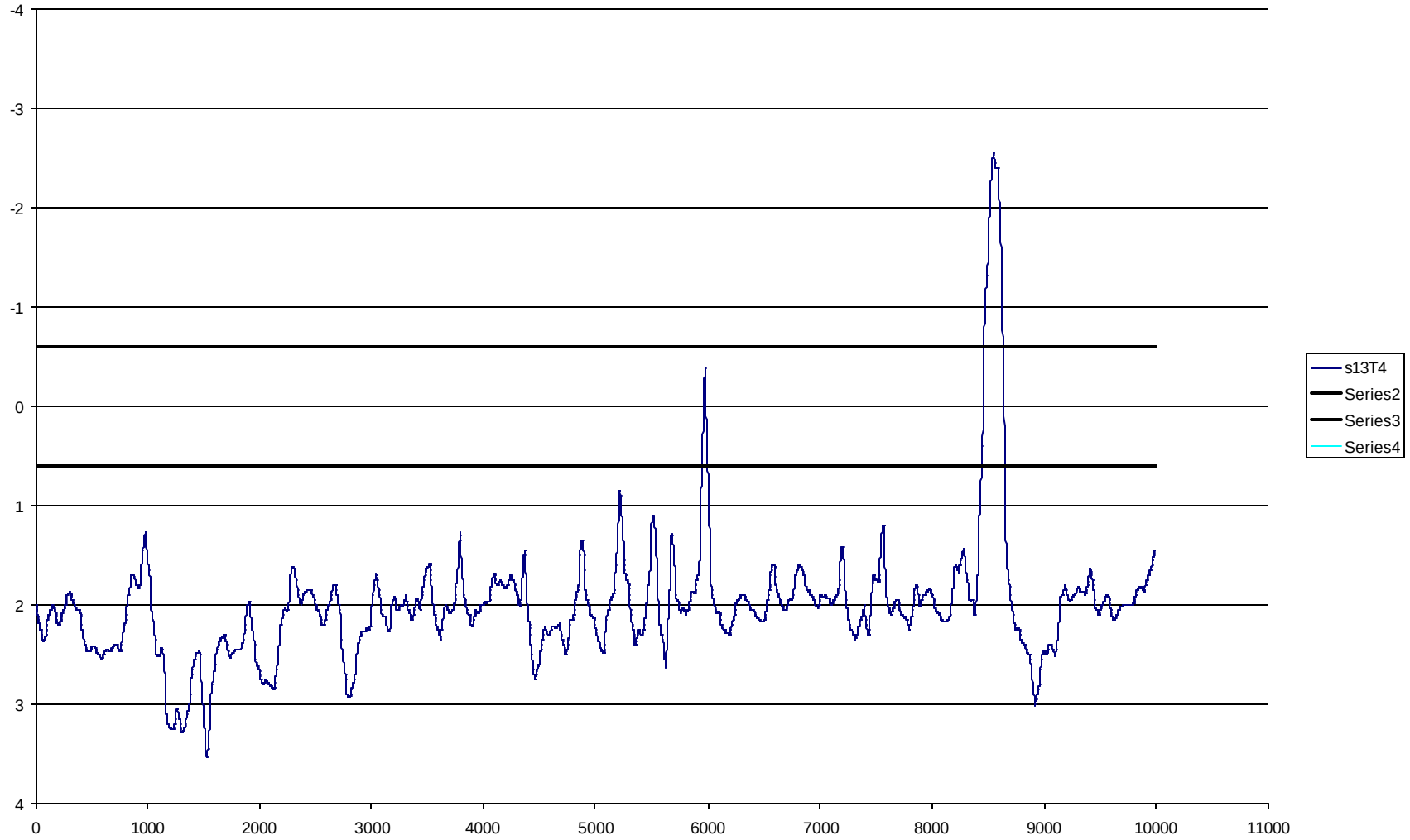

Figure A77: Lane position (in meters relative to center of road) for S13 driving for 10 km under Condition T4.

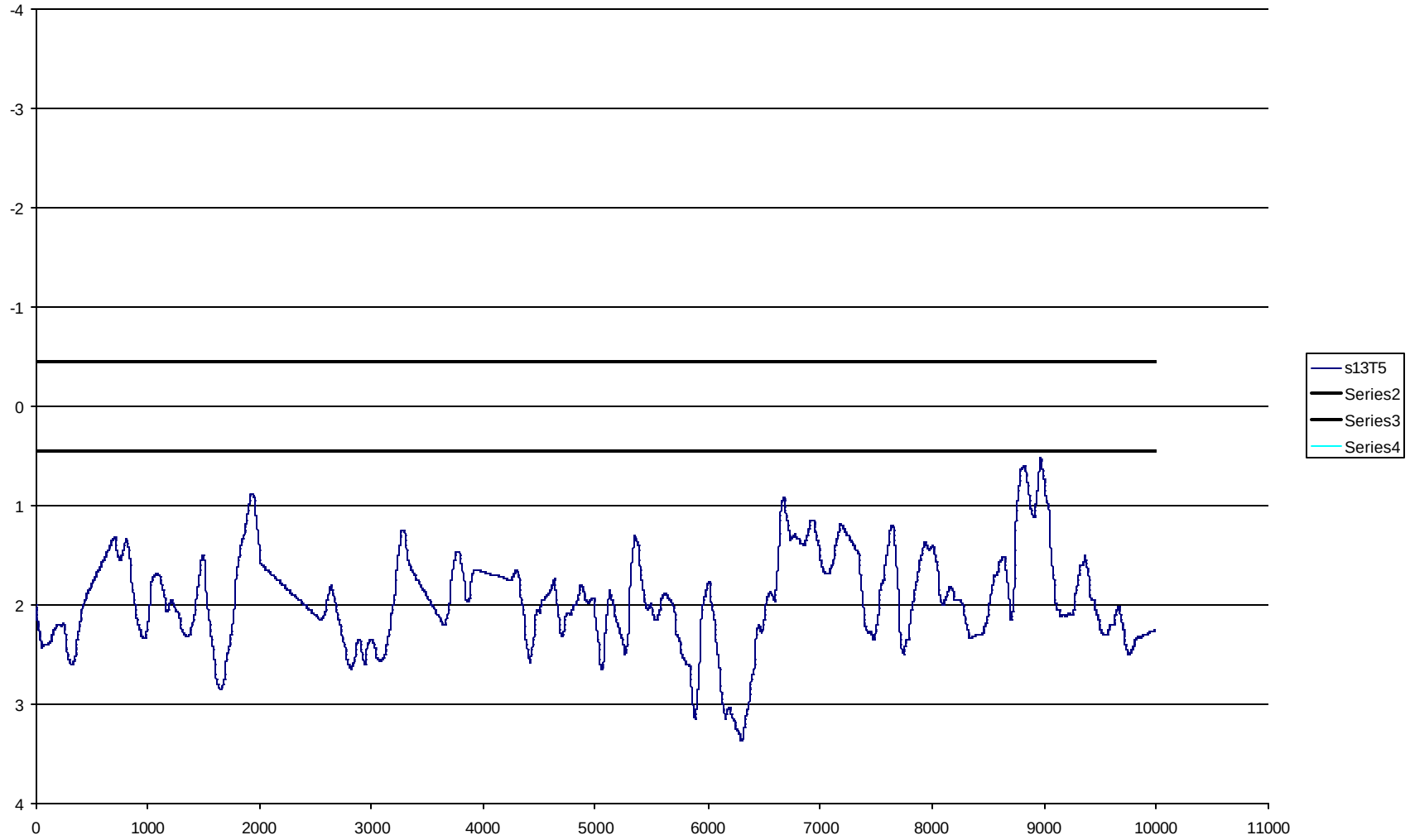

Figure A78: Lane position (in meters relative to center of road) for S13 driving for 10 km under Condition T5.

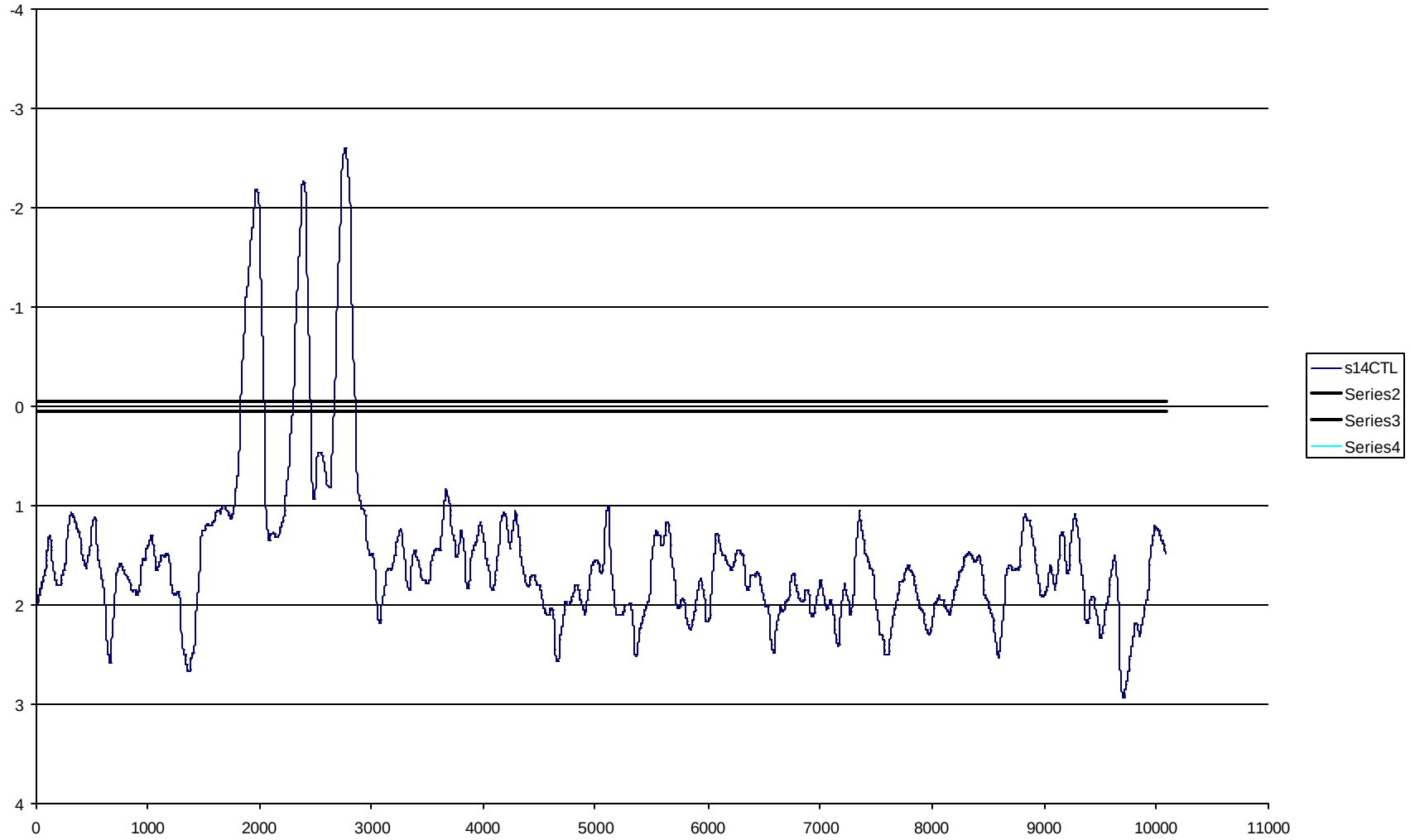

Figure A79: Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition CTL.

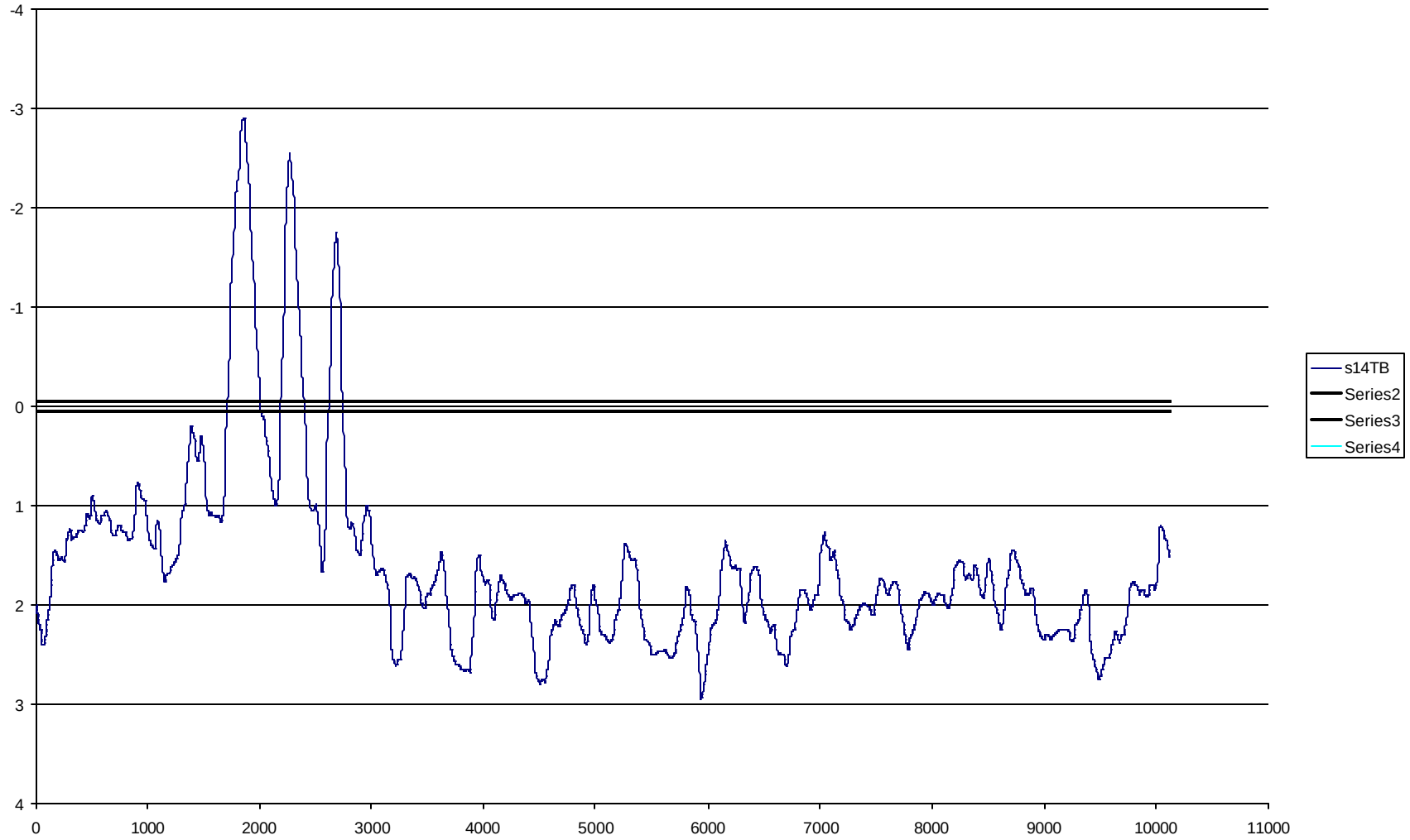

Figure A80: Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition TB.

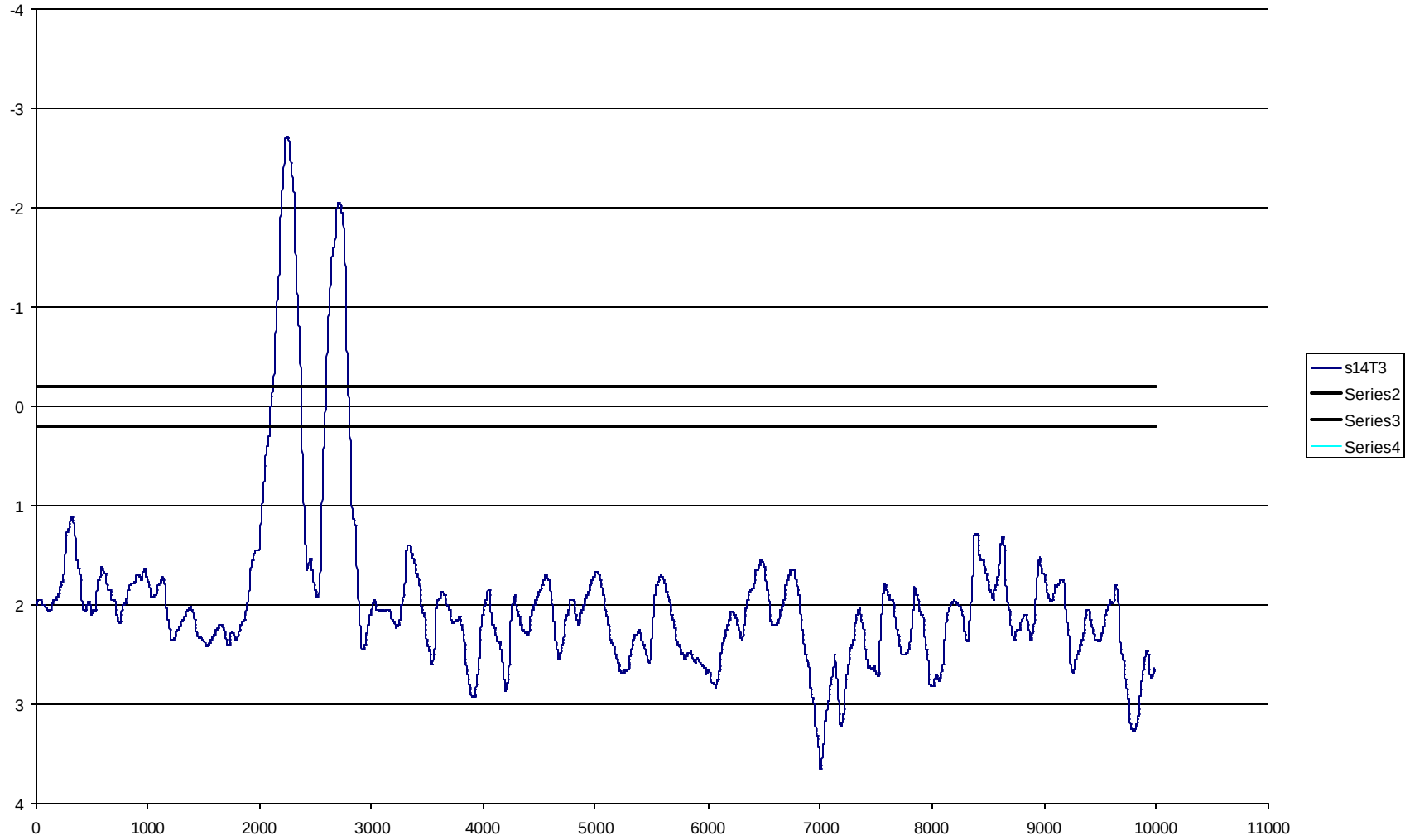

Figure A81: Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition T3.

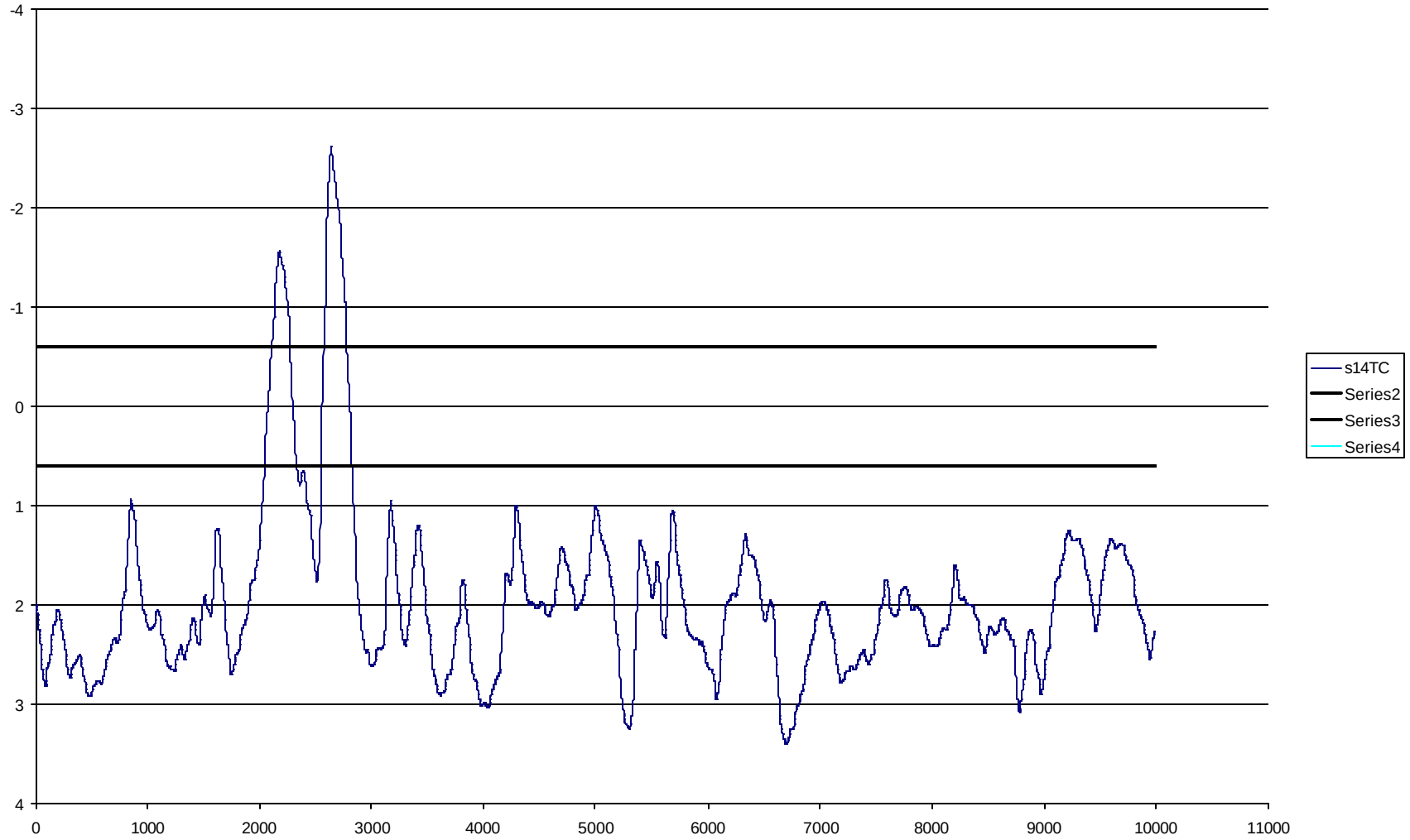

Figure A82: Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition TC.

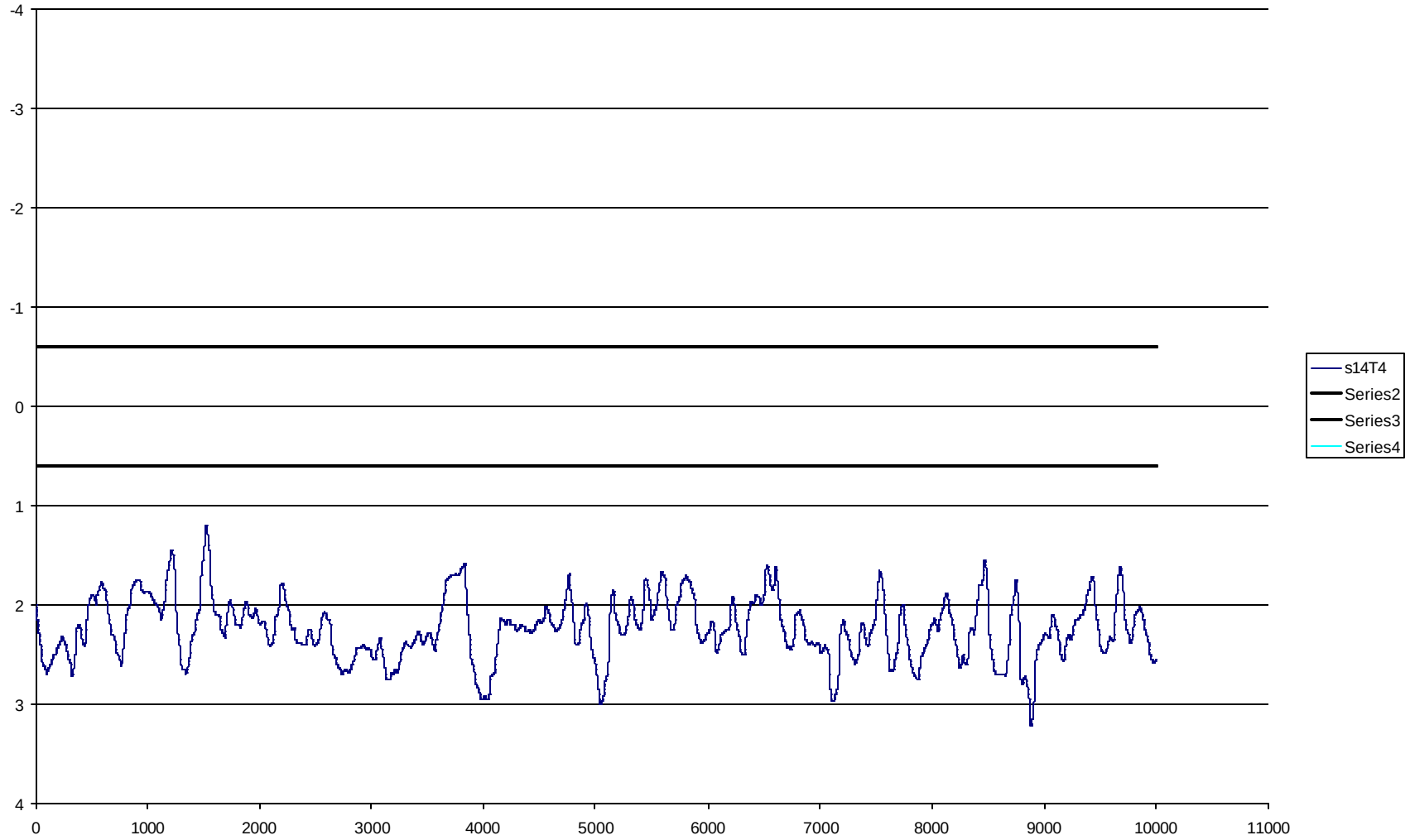

Figure A83: Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition T4.

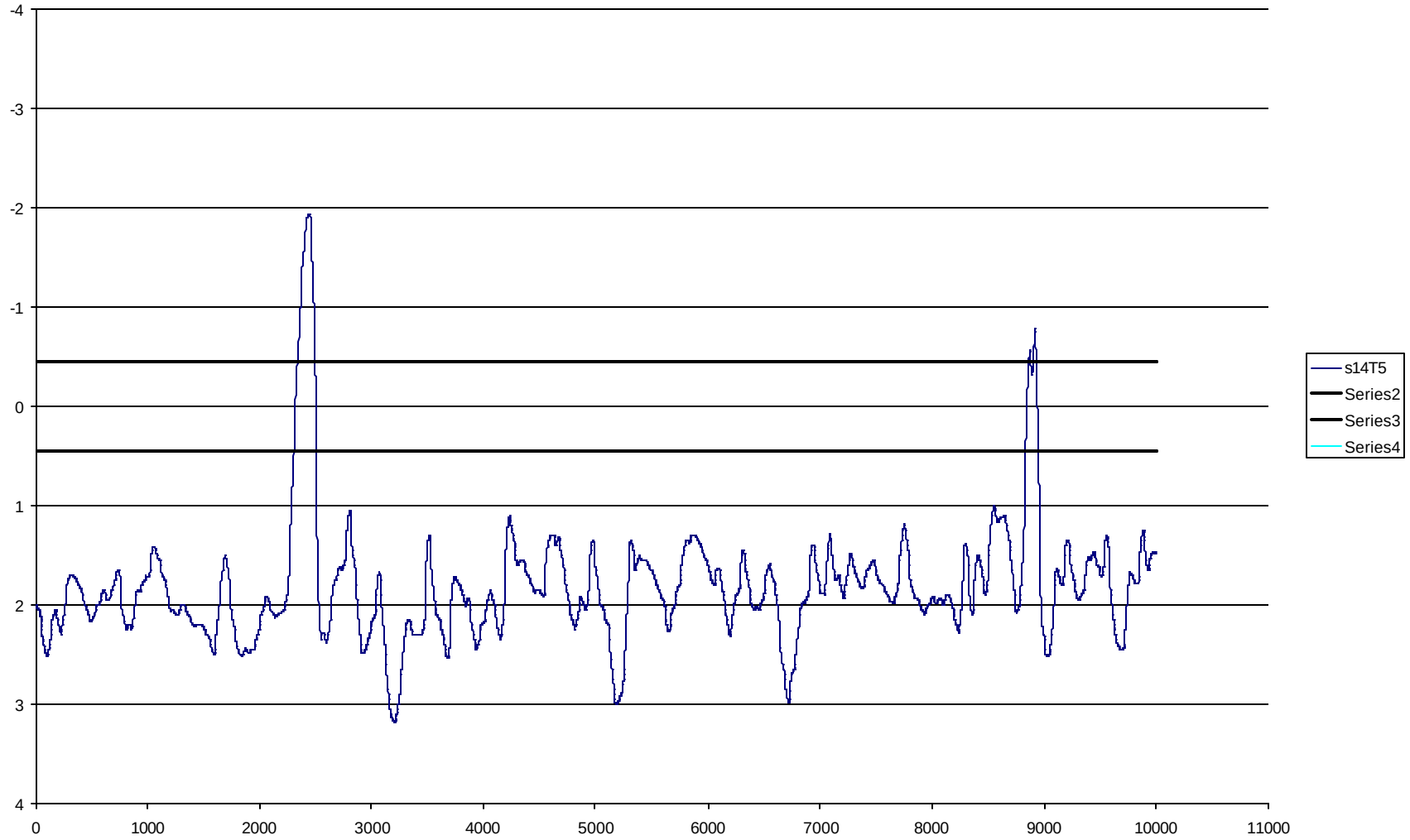

Figure A84: Lane position (in meters relative to center of road) for S14 driving for 10 km under Condition T5.

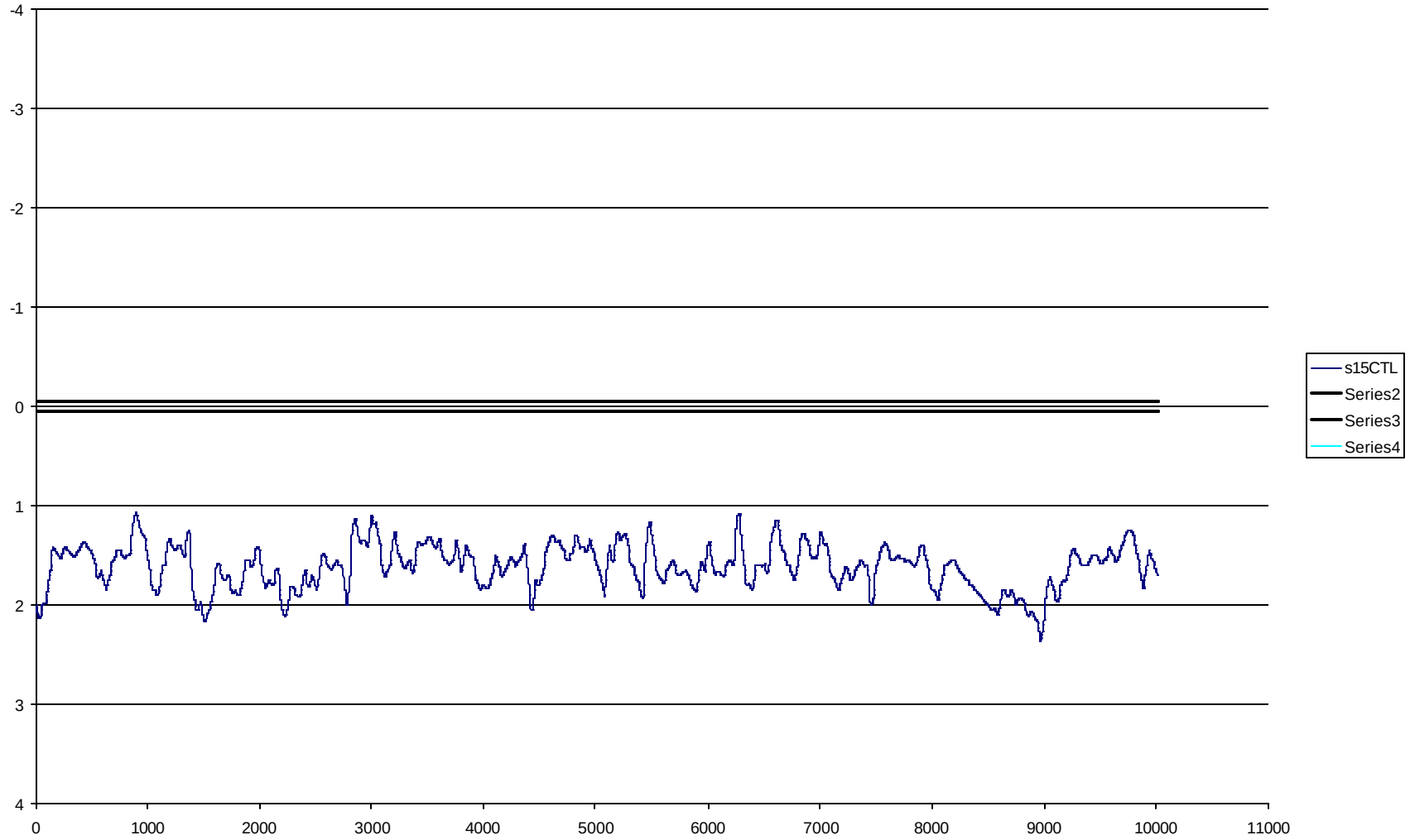

Figure A85: Lane position (in meters relative to center of road) for S15 driving for 10 km under Condition CTL.

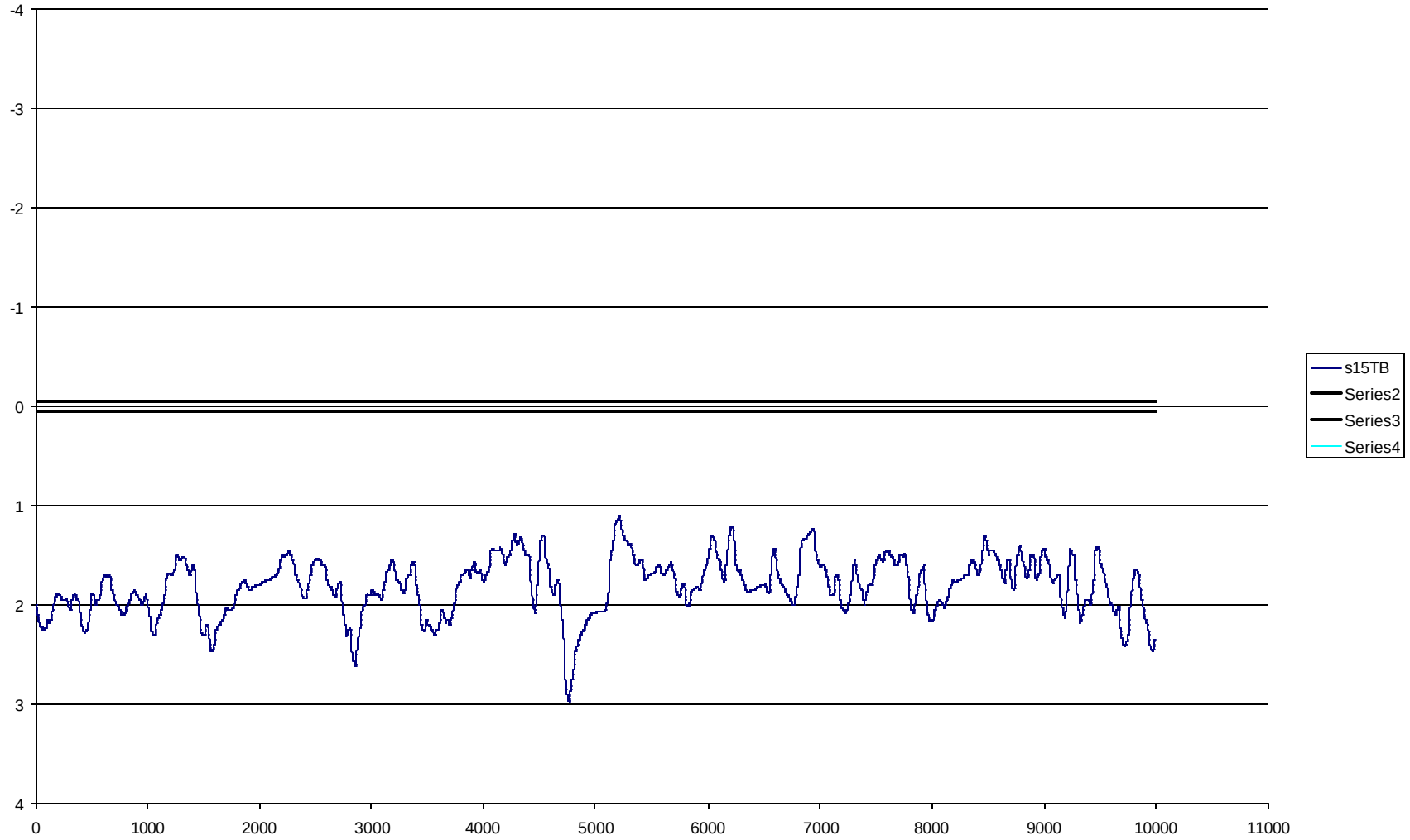

Figure A86: Lane position (in meters relative to center of road) for S15 driving for 10 km under Condition TB.

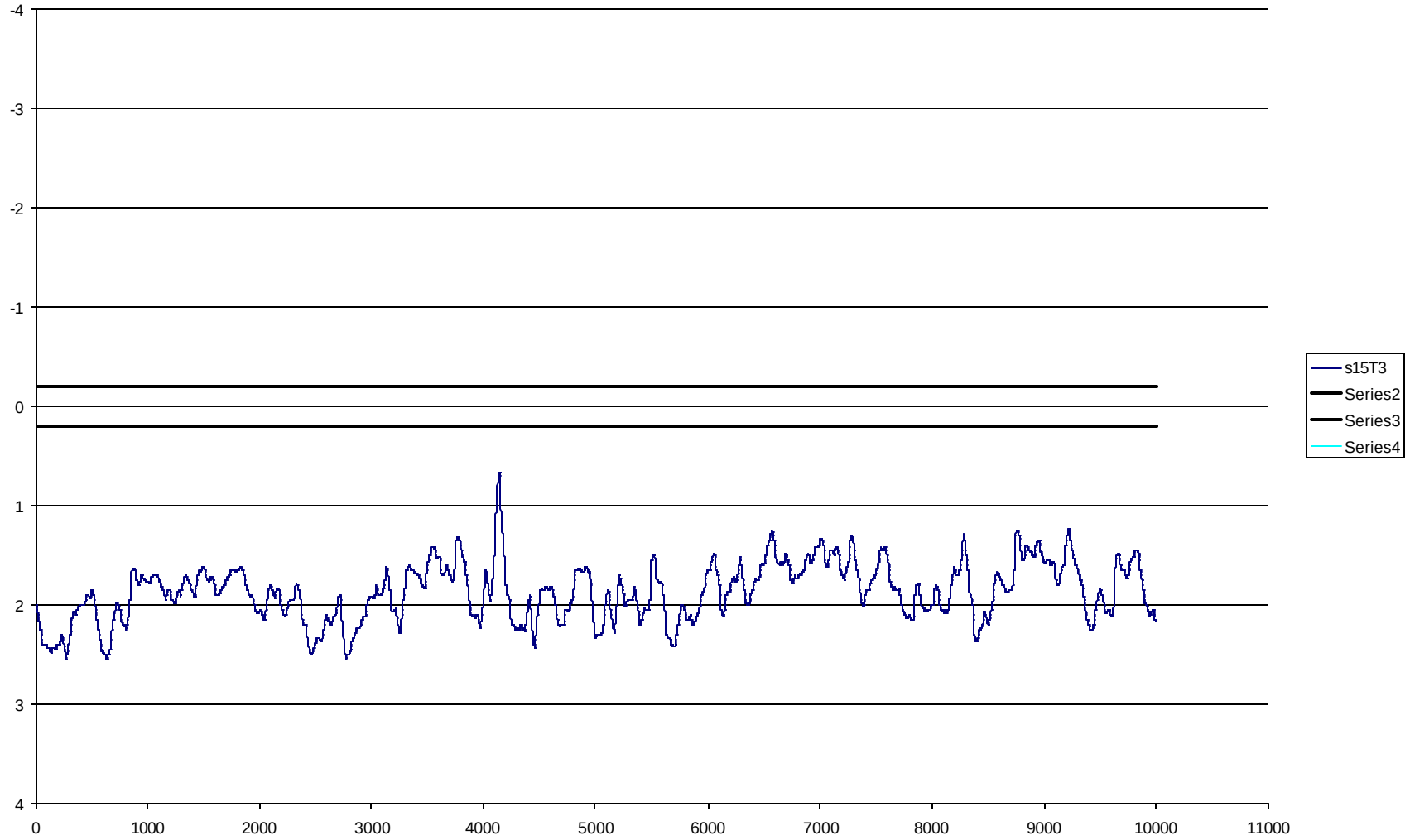

Figure A87: Lane position (in meters relative to center of road) for S15 driving for 10 km under Condition T3.

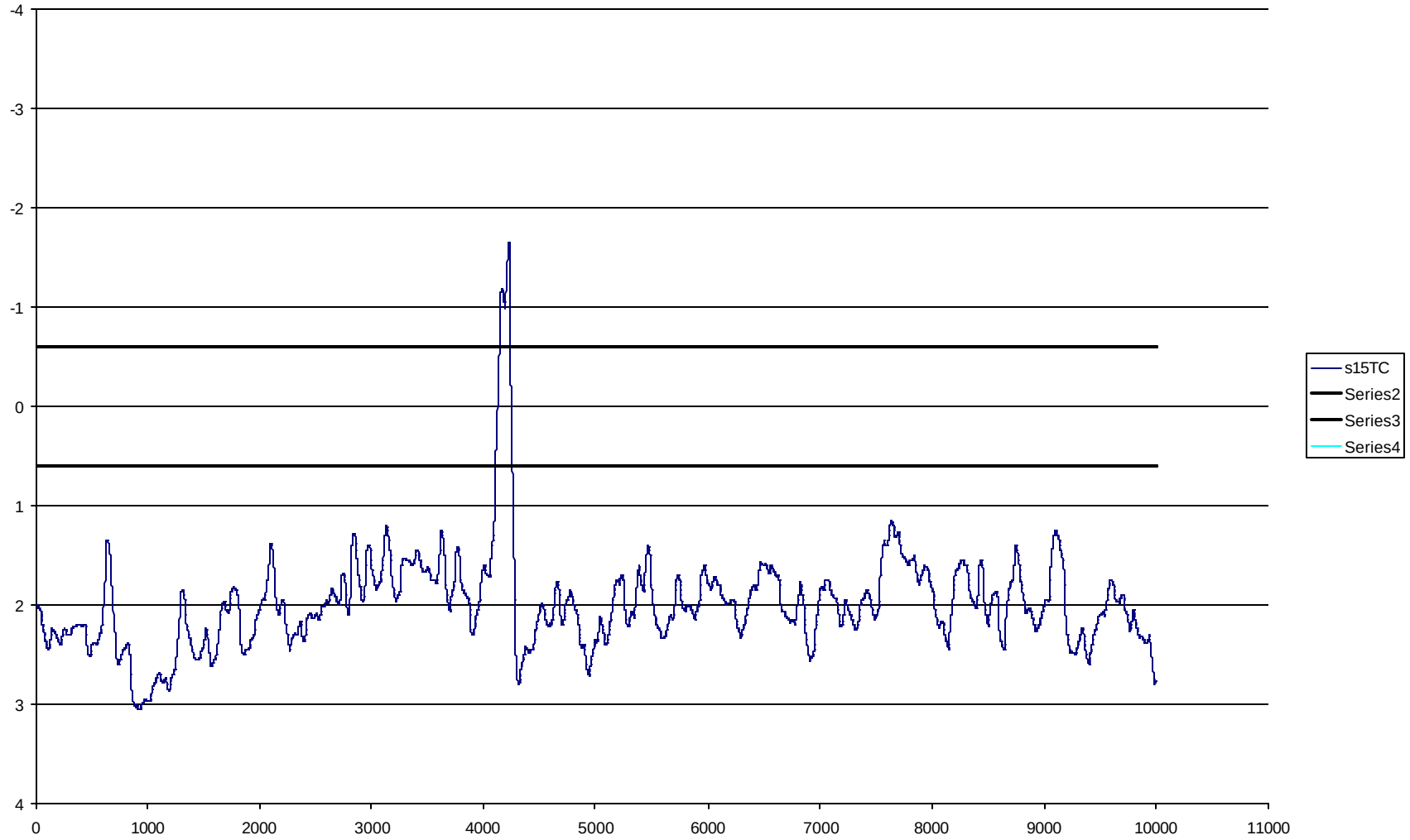

Figure A88: Lane position (in meters relative to center of road) for S15 driving for 10 km under Condition TC.

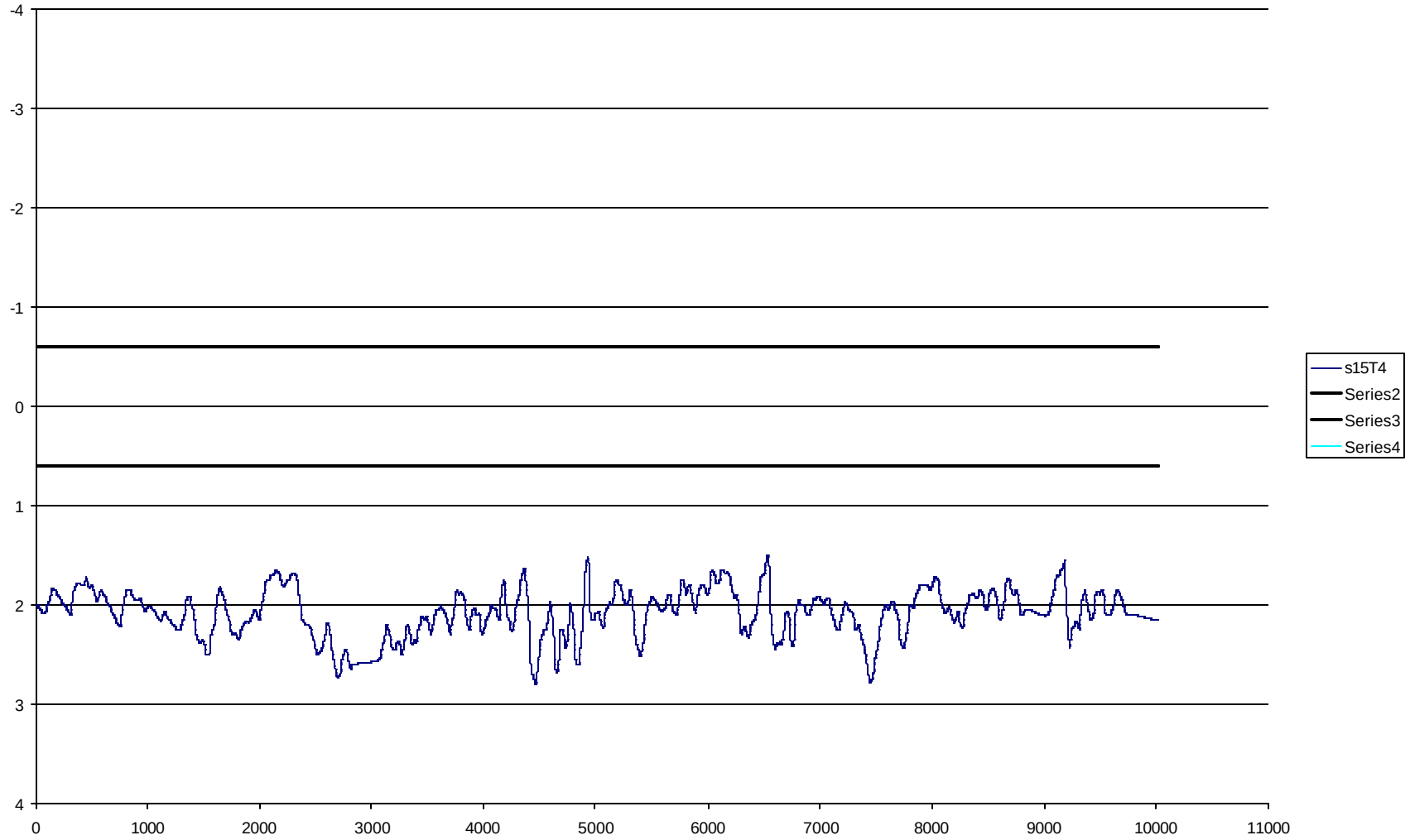

Figure A89: Lane position (in meters relative to center of road) for S15 driving for 10 km under Condition T4.

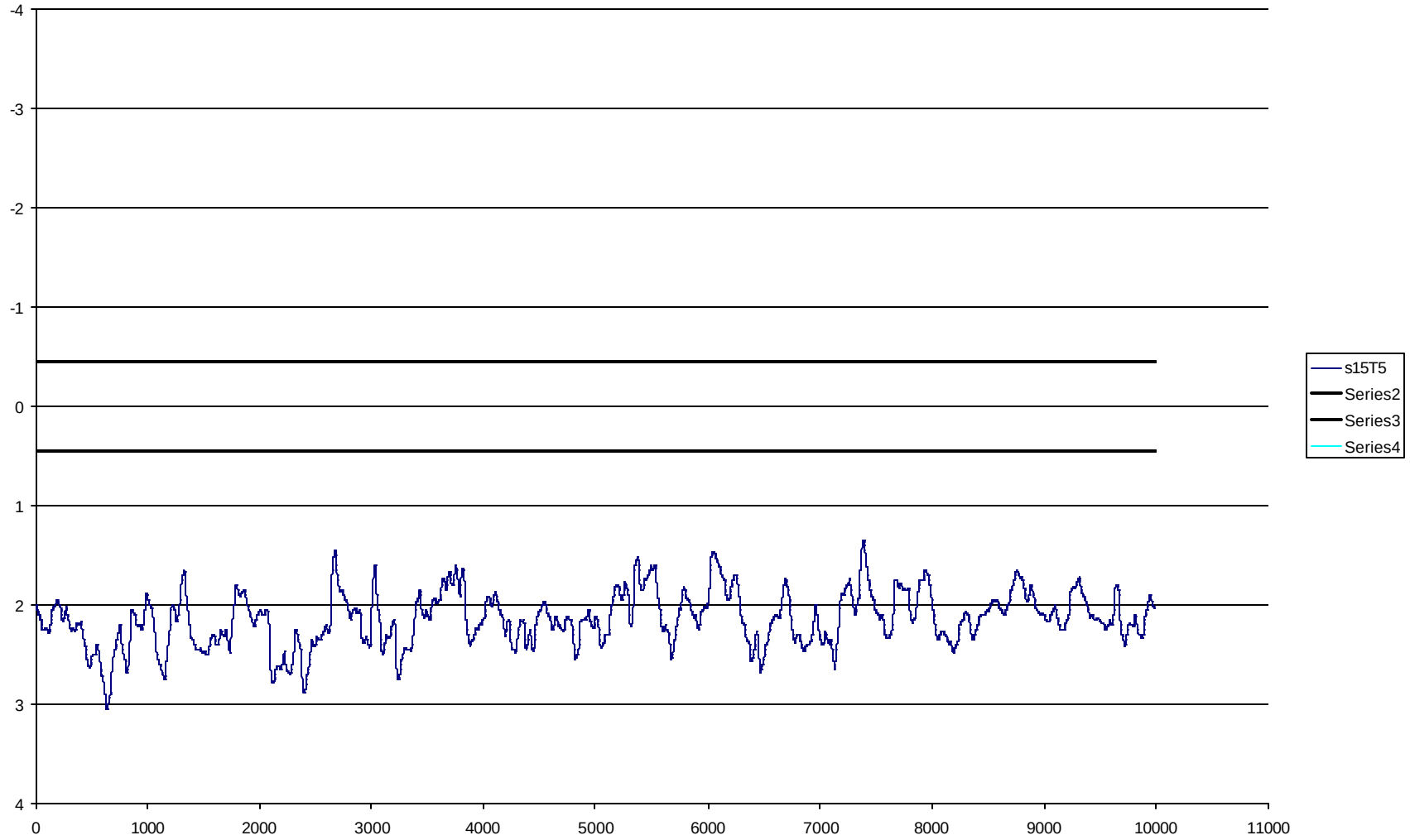

Figure A90: Lane position (in meters relative to center of road) for S15 driving for 10 km under Condition T5.

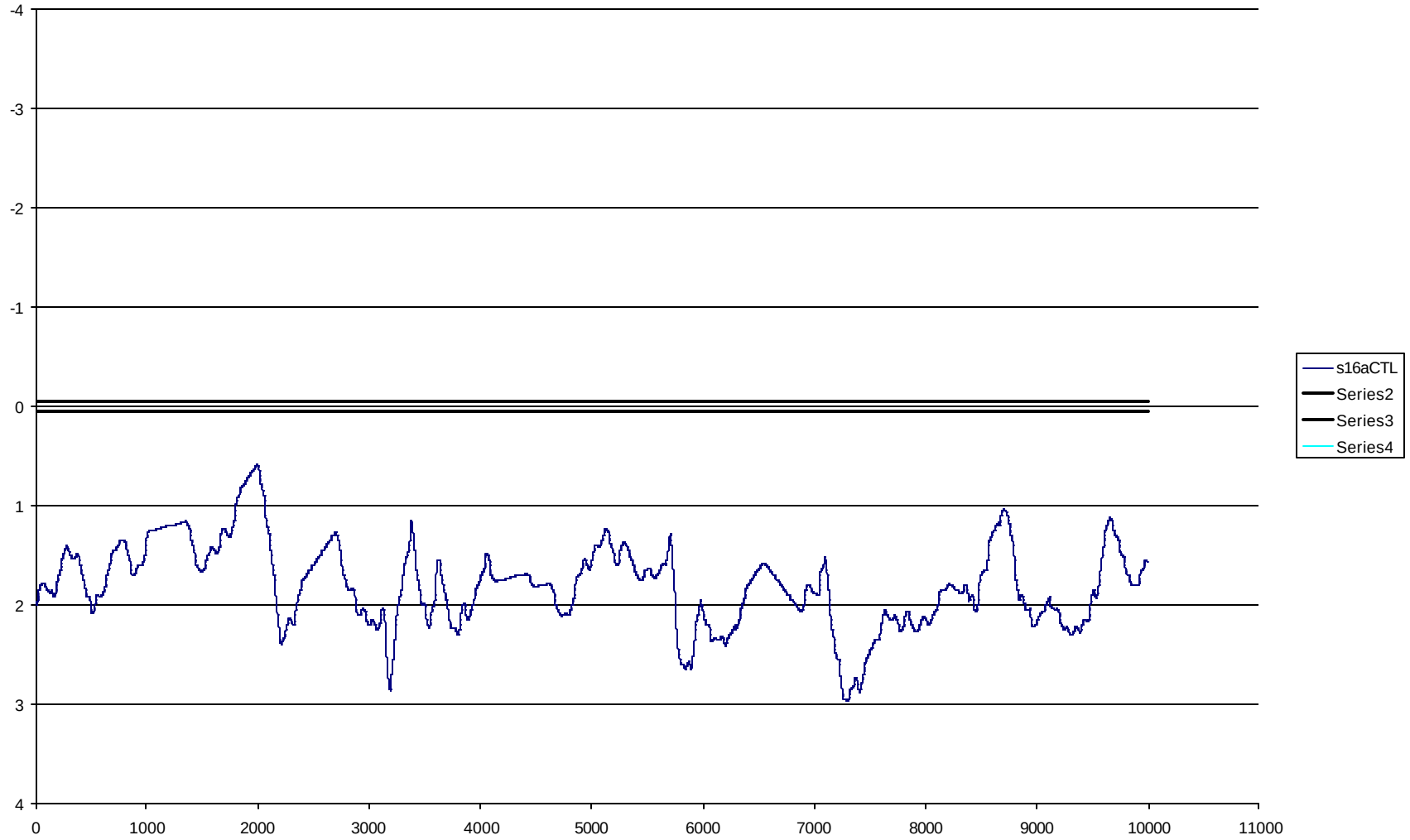

Figure A91: Lane position (in meters relative to center of road) for S16 driving for 10 km under Condition CTL.

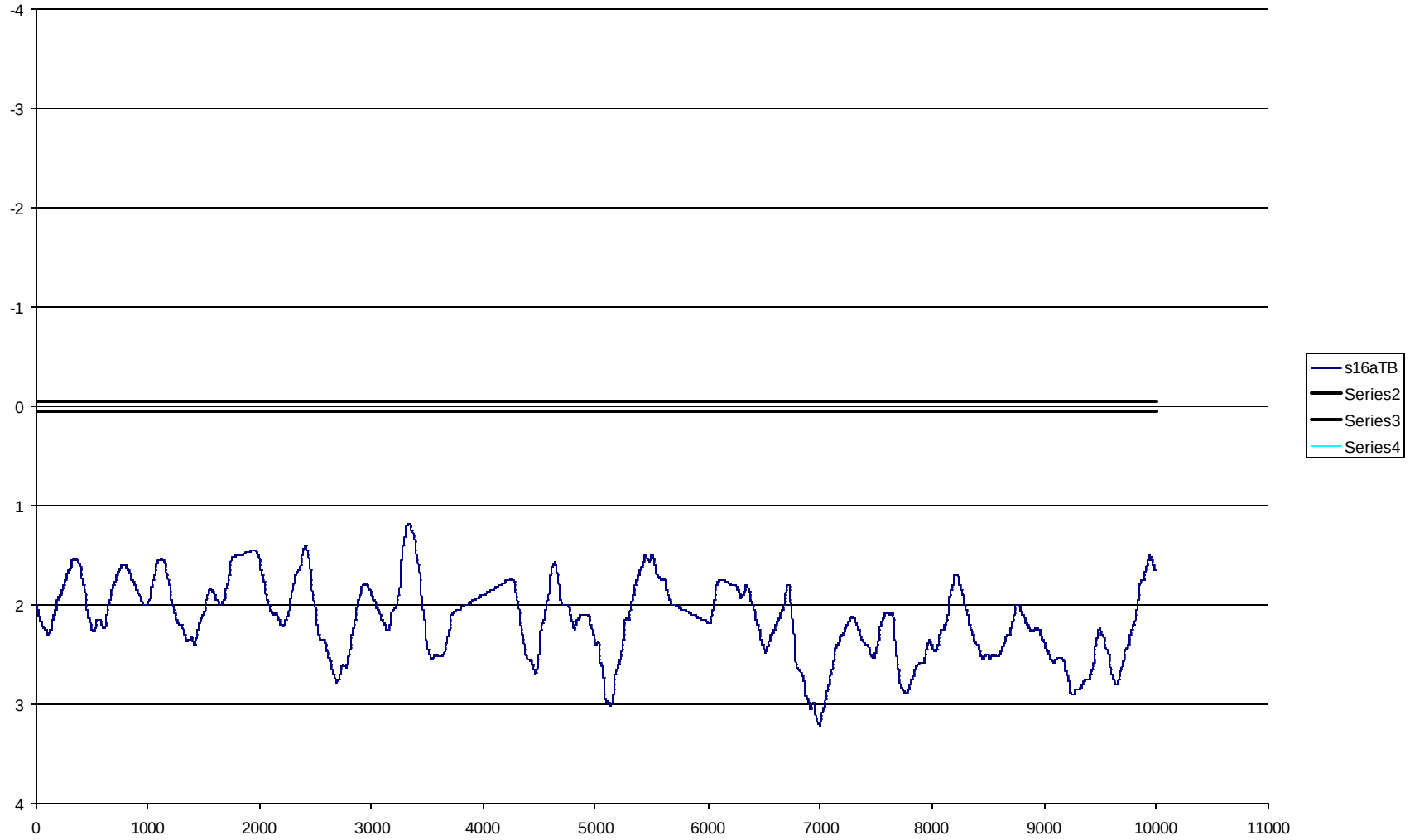

Figure A92: Lane position (in meters relative to center of road) for S16 driving for 10 km under Condition TB.

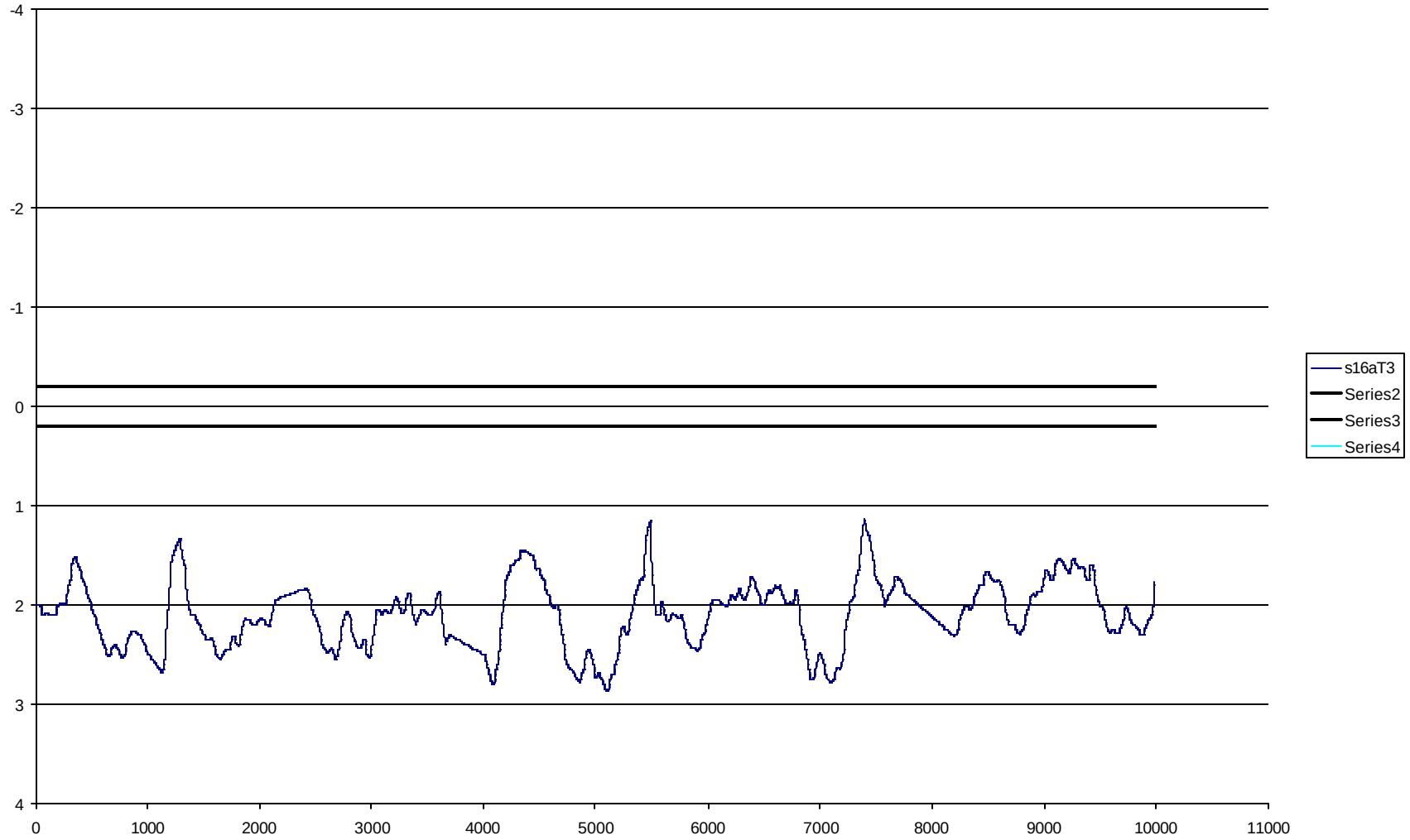

Figure A93: Lane position (in meters relative to center of road) for S16 driving for 10 km under Condition T3.

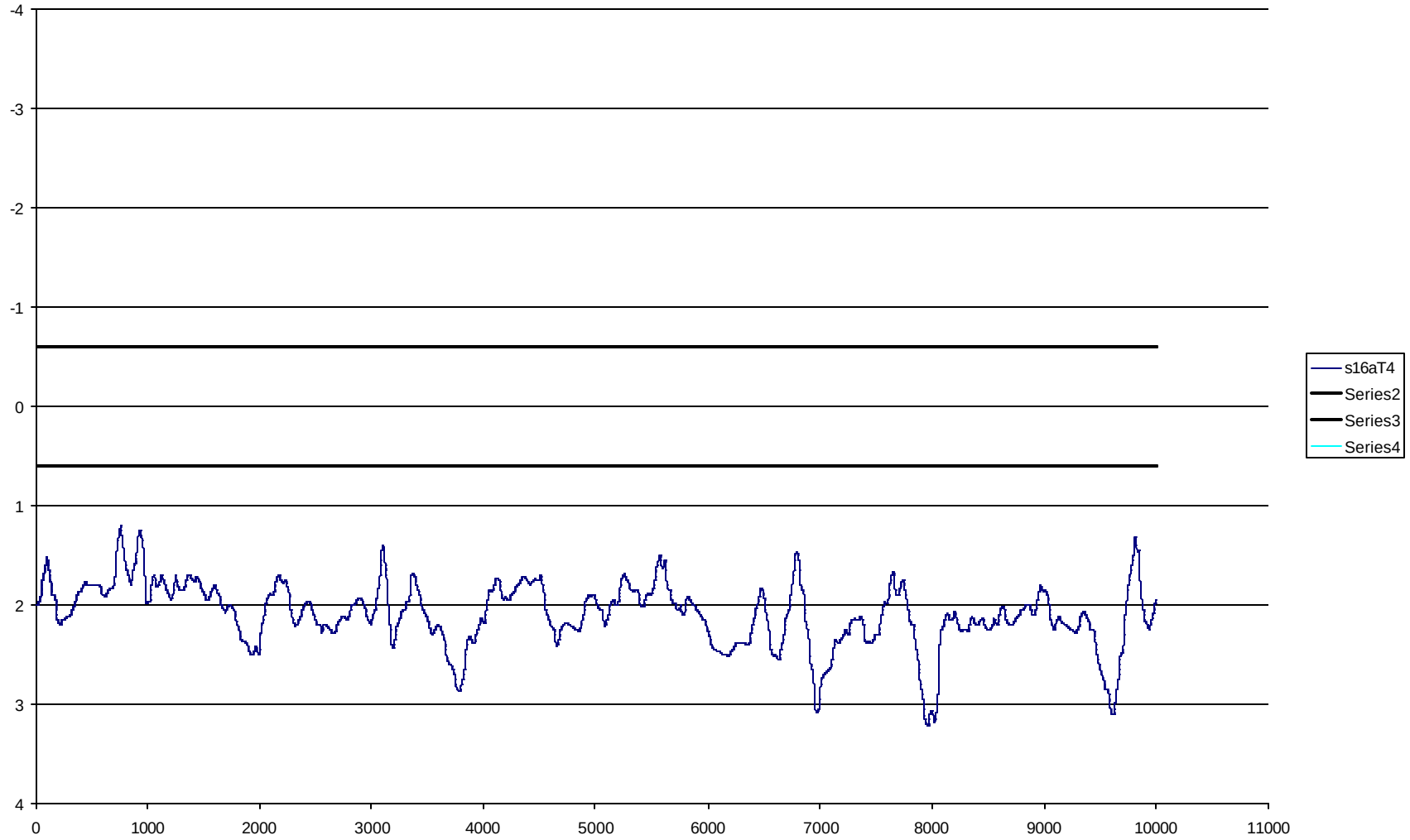

Figure A94: Lane position (in meters relative to center of road) for S16 driving for 10 km under Condition T4.

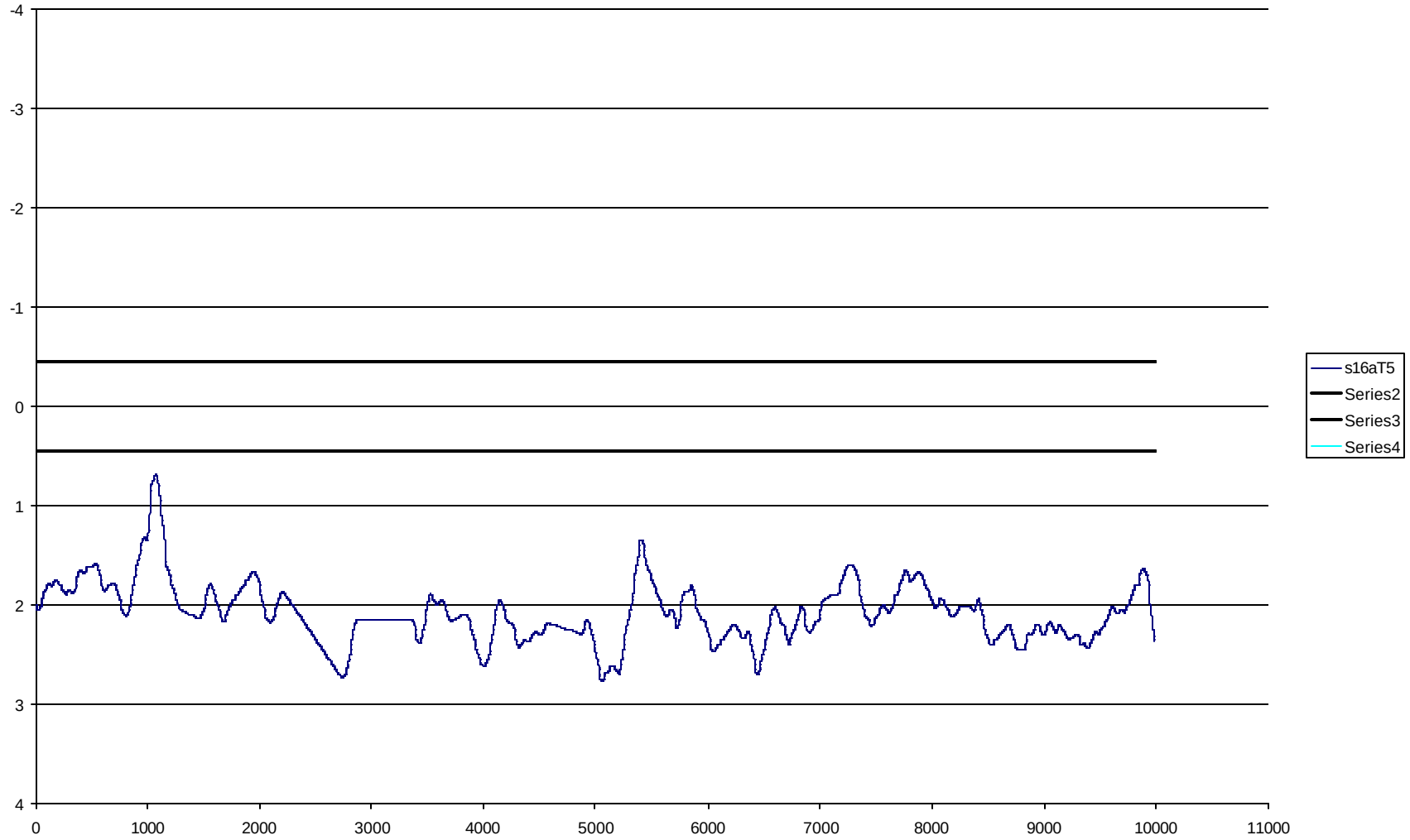

Figure A95: Lane position (in meters relative to center of road) for S16 driving for 10 km under Condition T5.

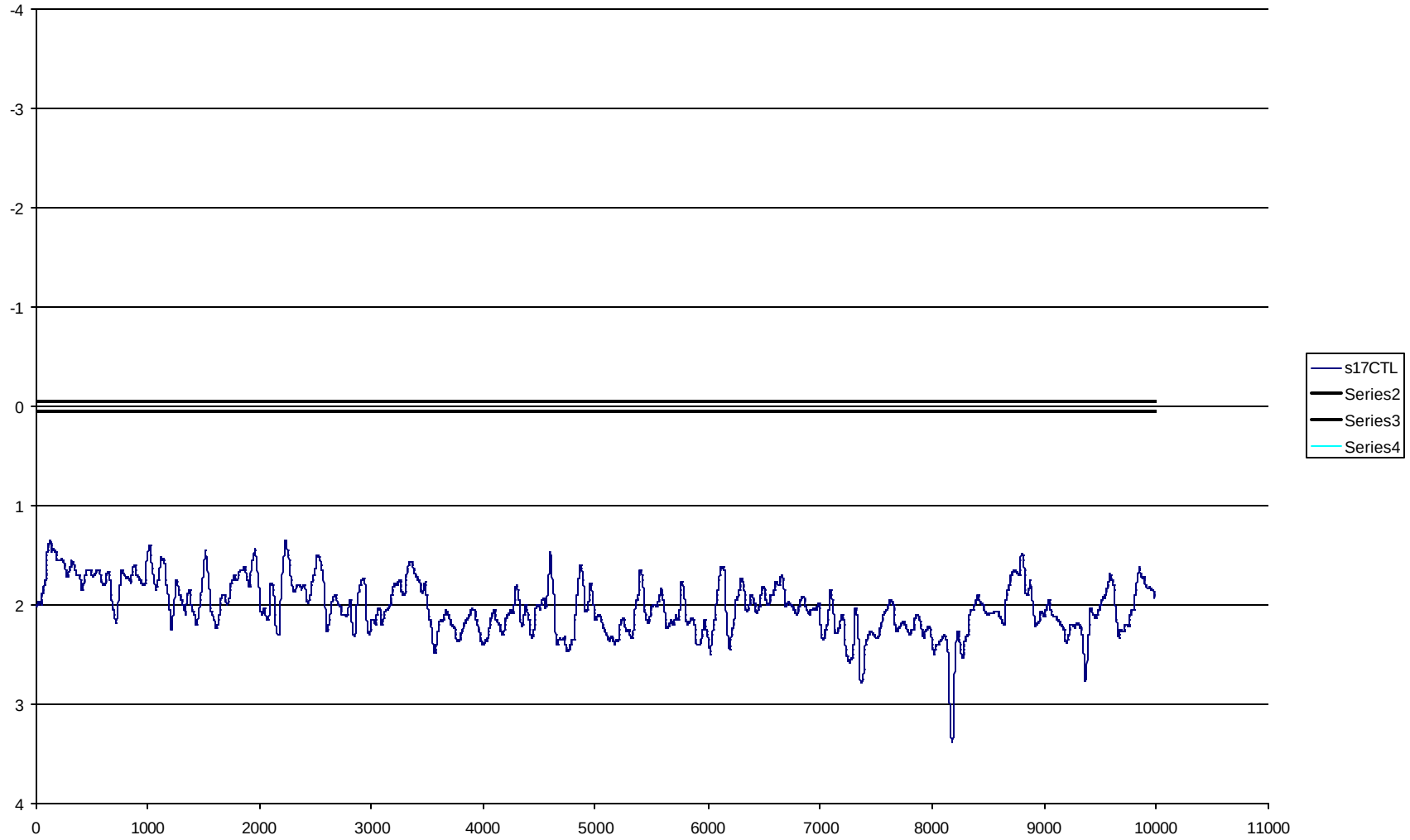

Figure A96: Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition CTL.

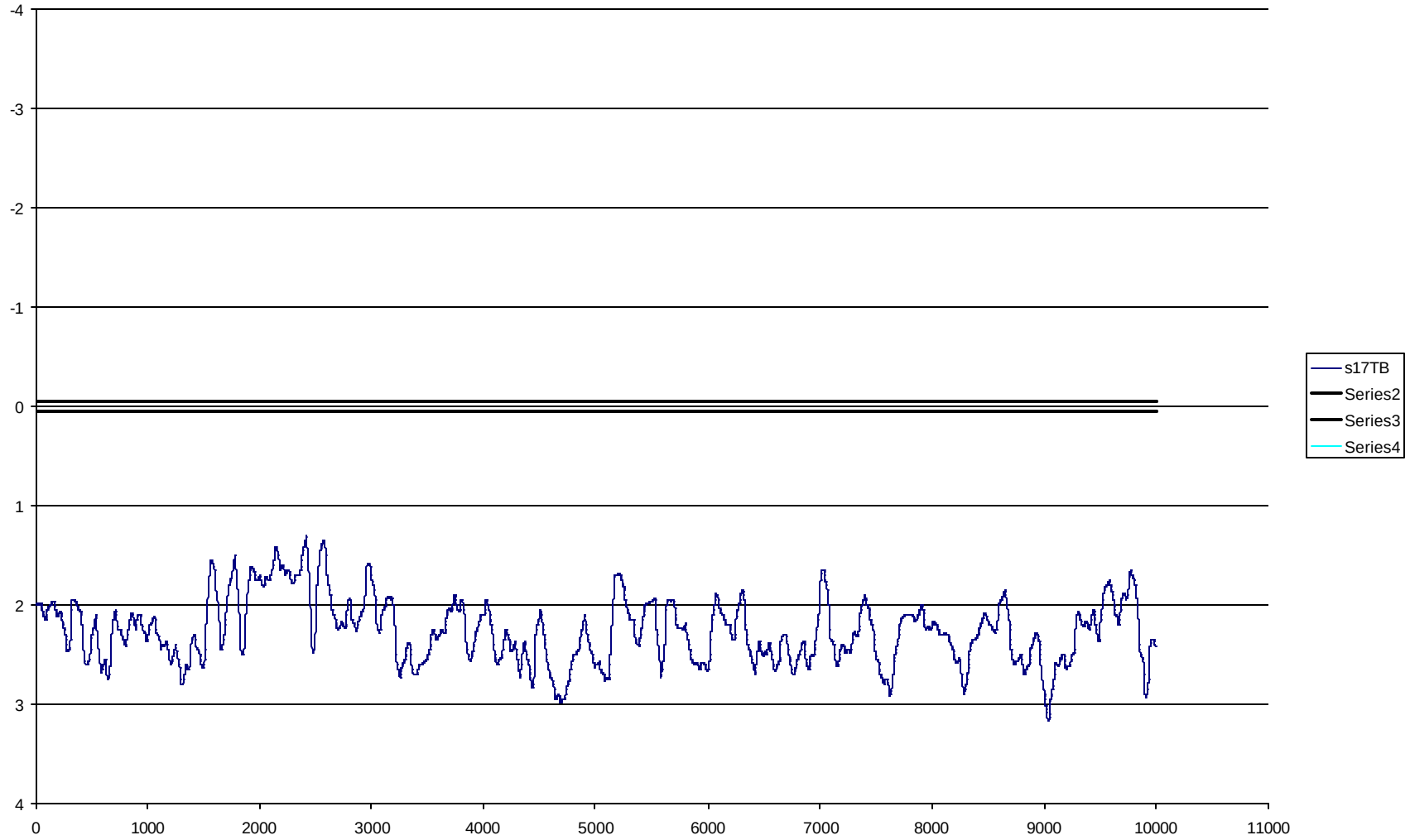

Figure A97: Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition TB.

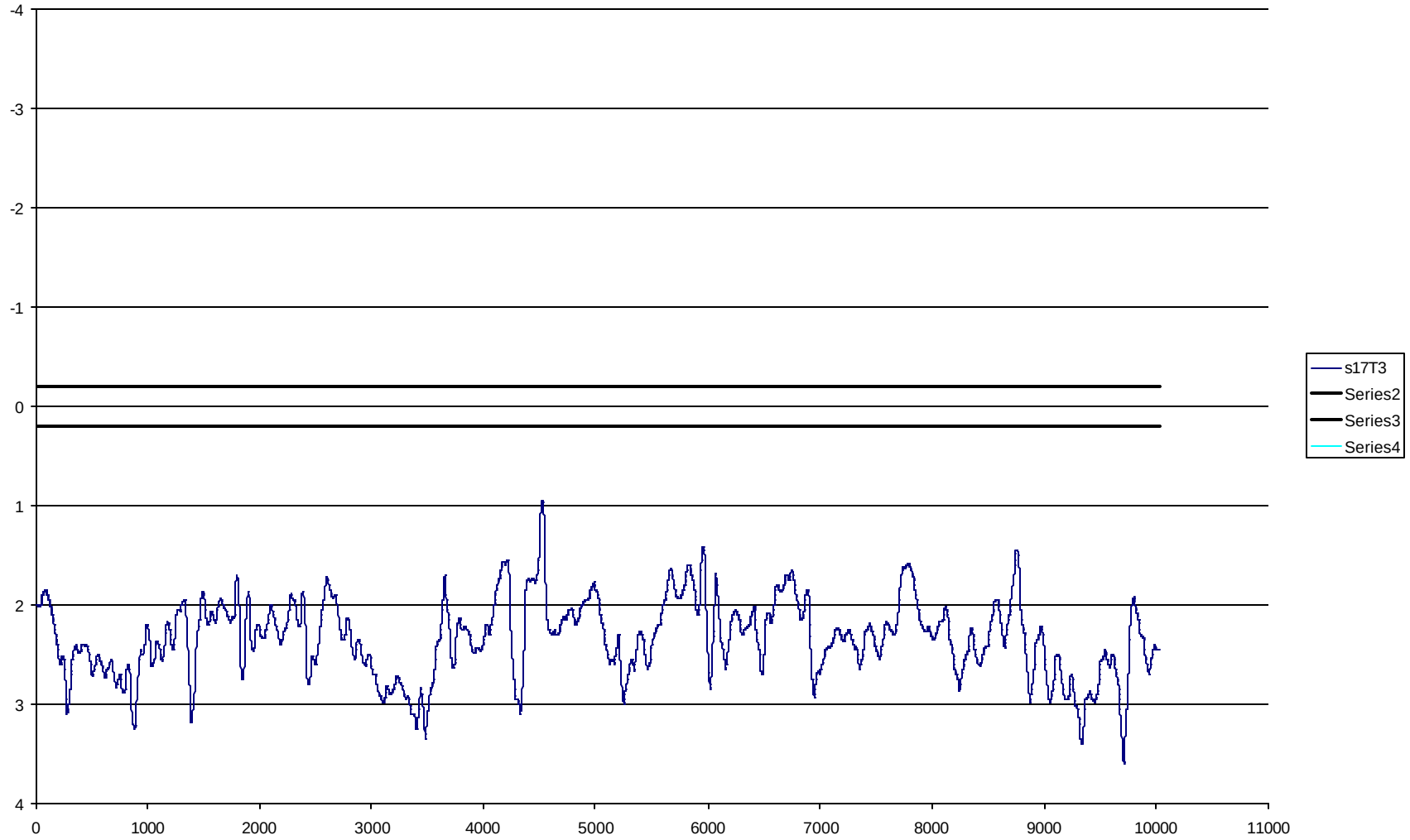

Figure A98: Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition T3.

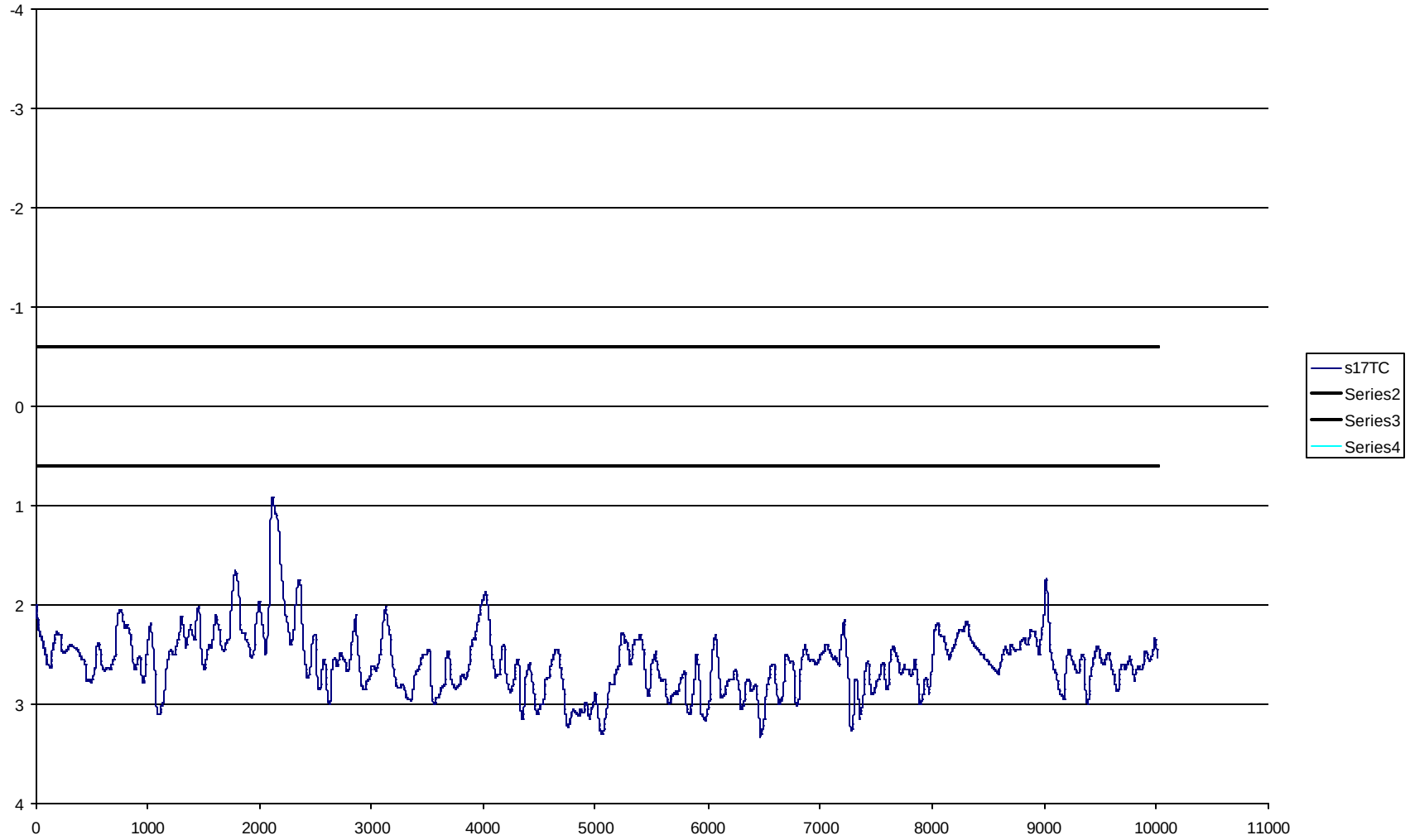

Figure A99: Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition TC.

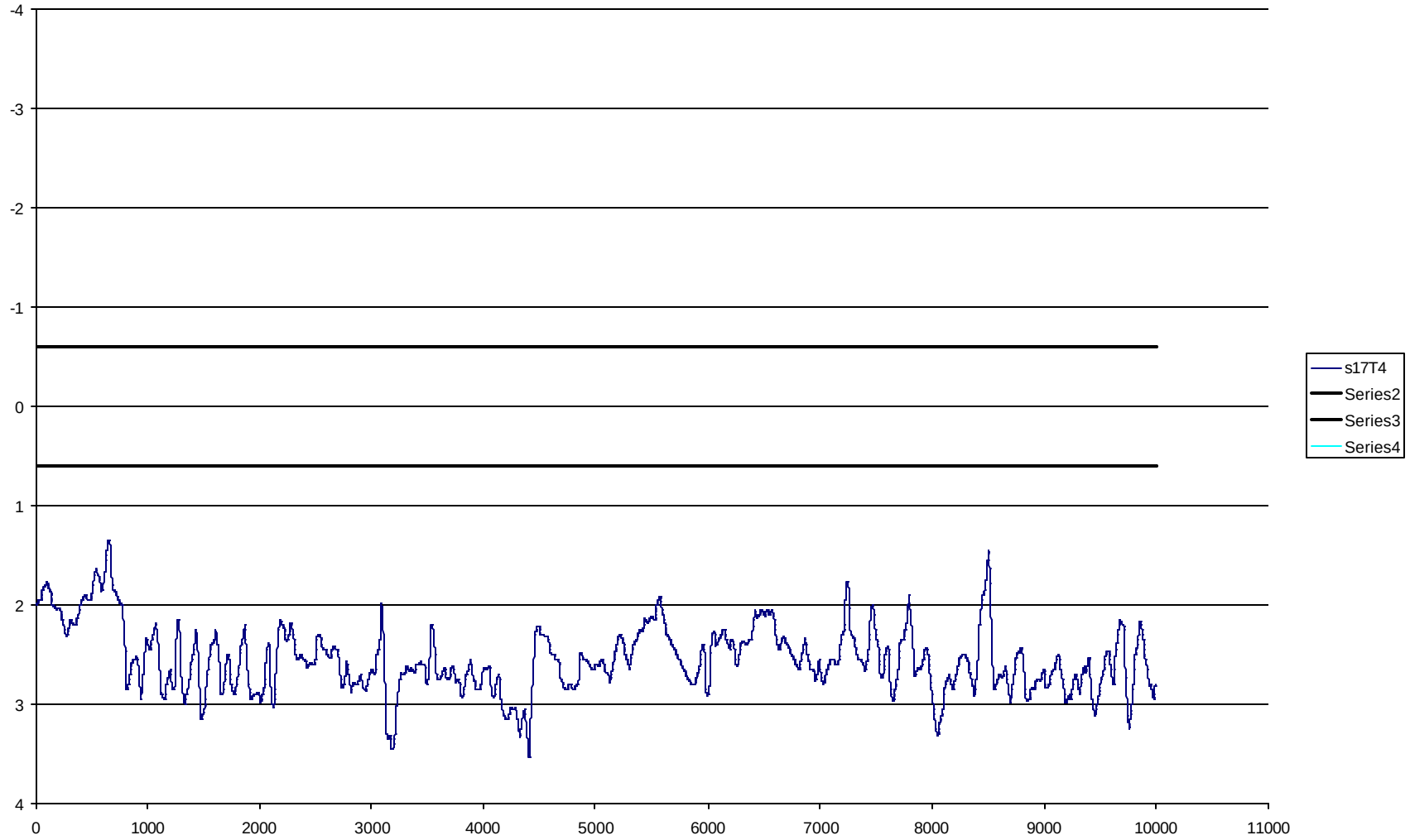

Figure A100: Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition T4.

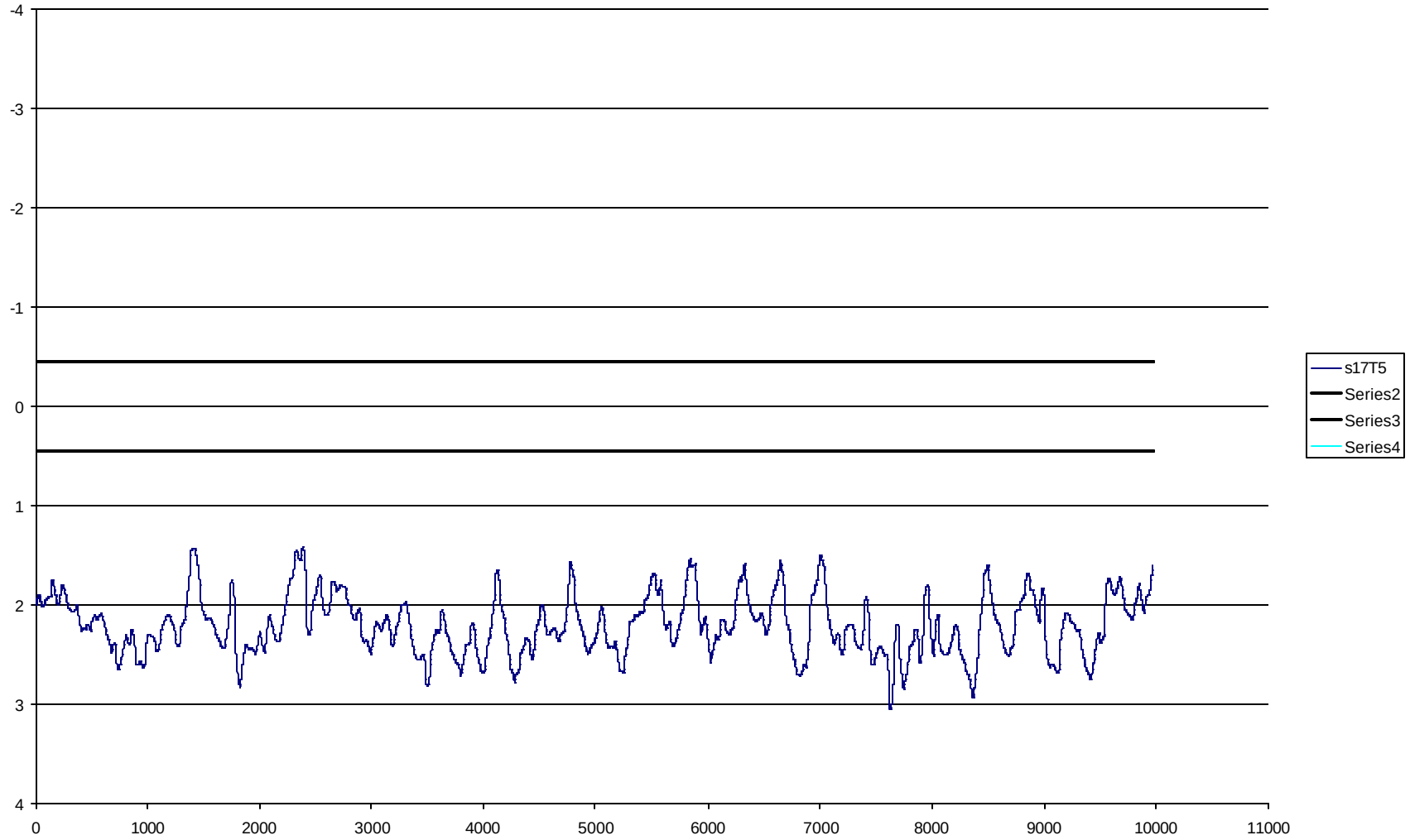

Figure A101: Lane position (in meters relative to center of road) for S17 driving for 10 km under Condition T5.

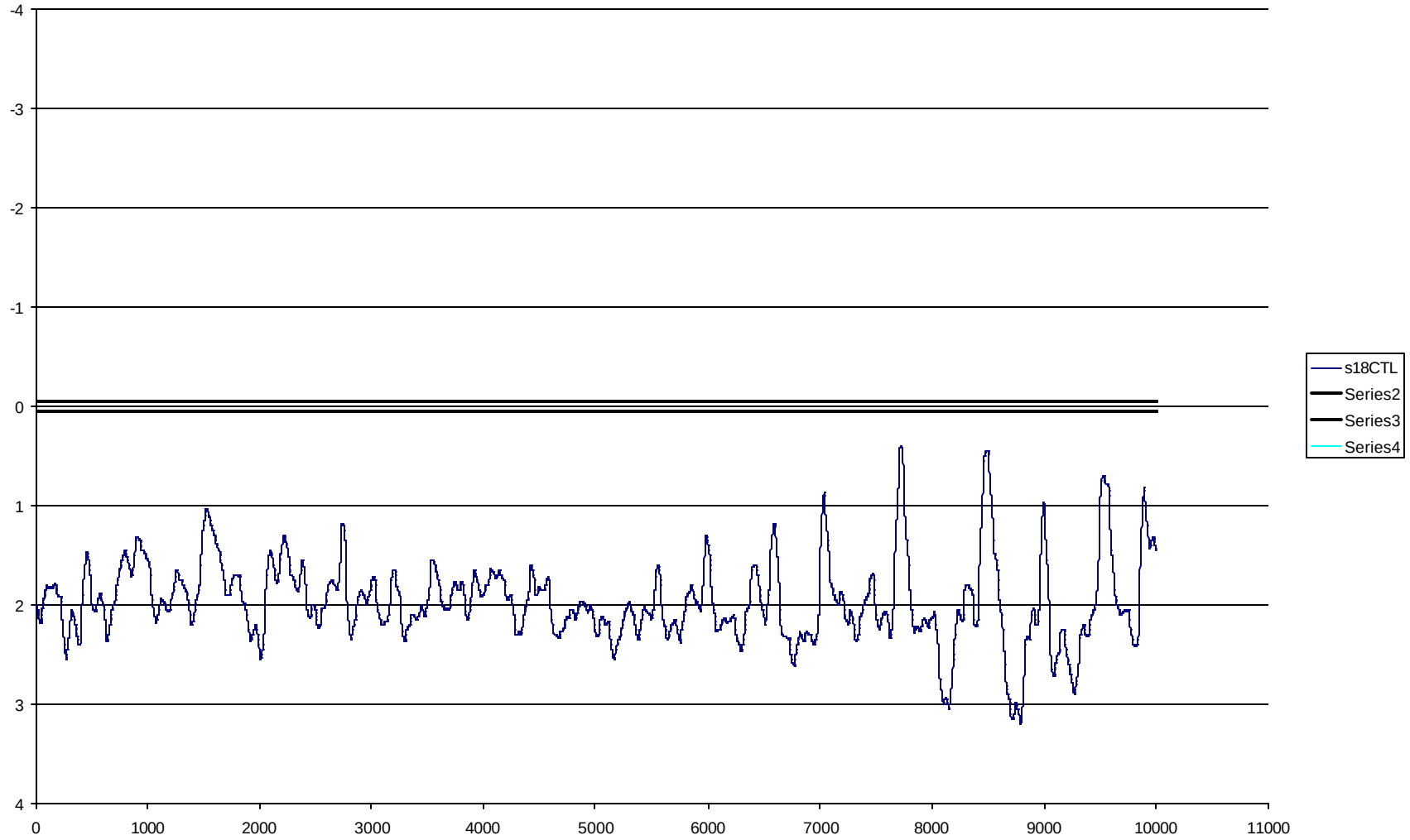

Figure A102: Lane position (in meters relative to center of road) for S18 driving for 10 km under Condition CTL.

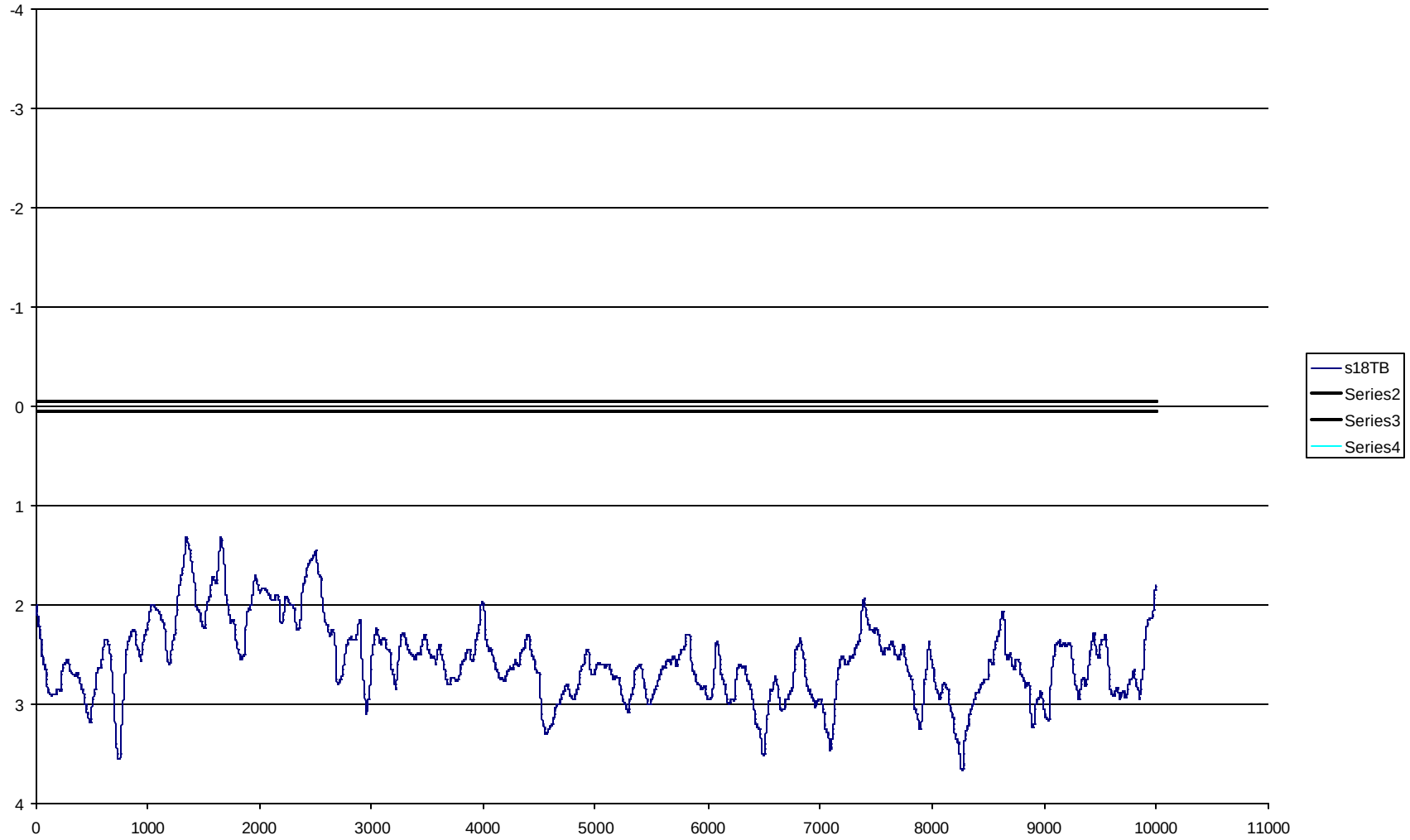

Figure A103: Lane position (in meters relative to center of road) for S18 driving for 10 km under Condition TB.

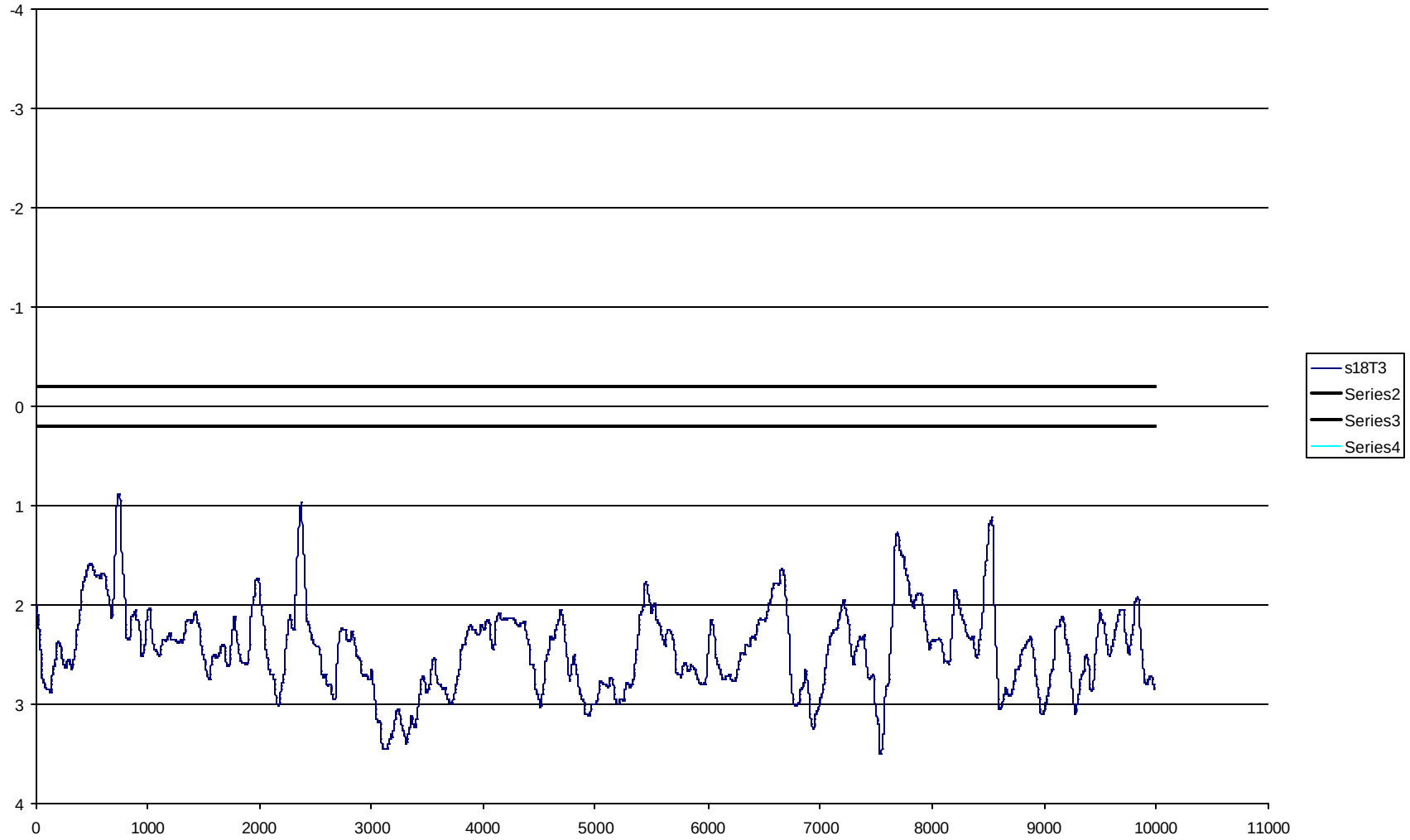

Figure A104: Lane position (in meters relative to center of road) for S18 driving for 10 km under Condition T3.

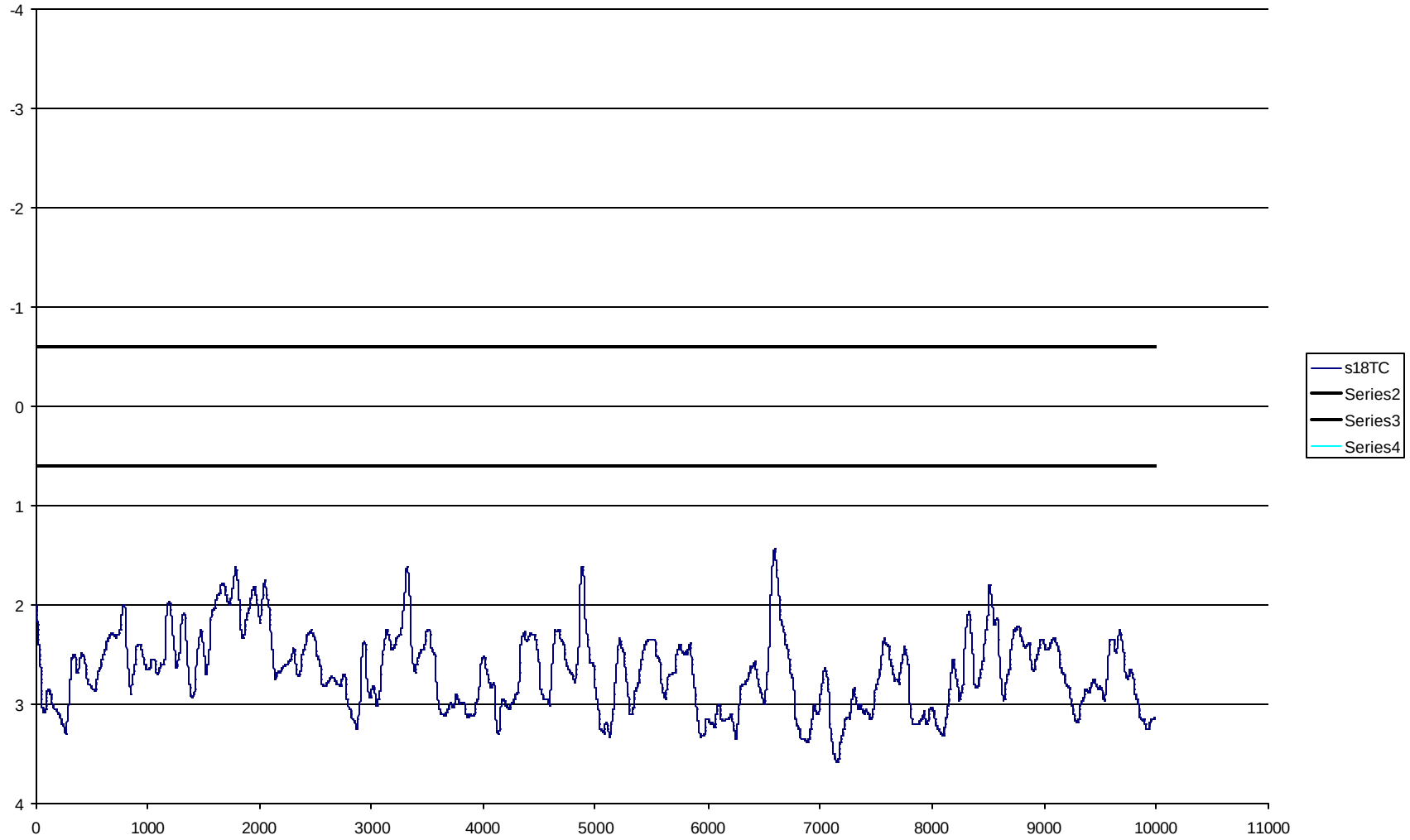

Figure A105: Lane position (in meters relative to center of road) for S18 driving for 10 km under Condition TC.

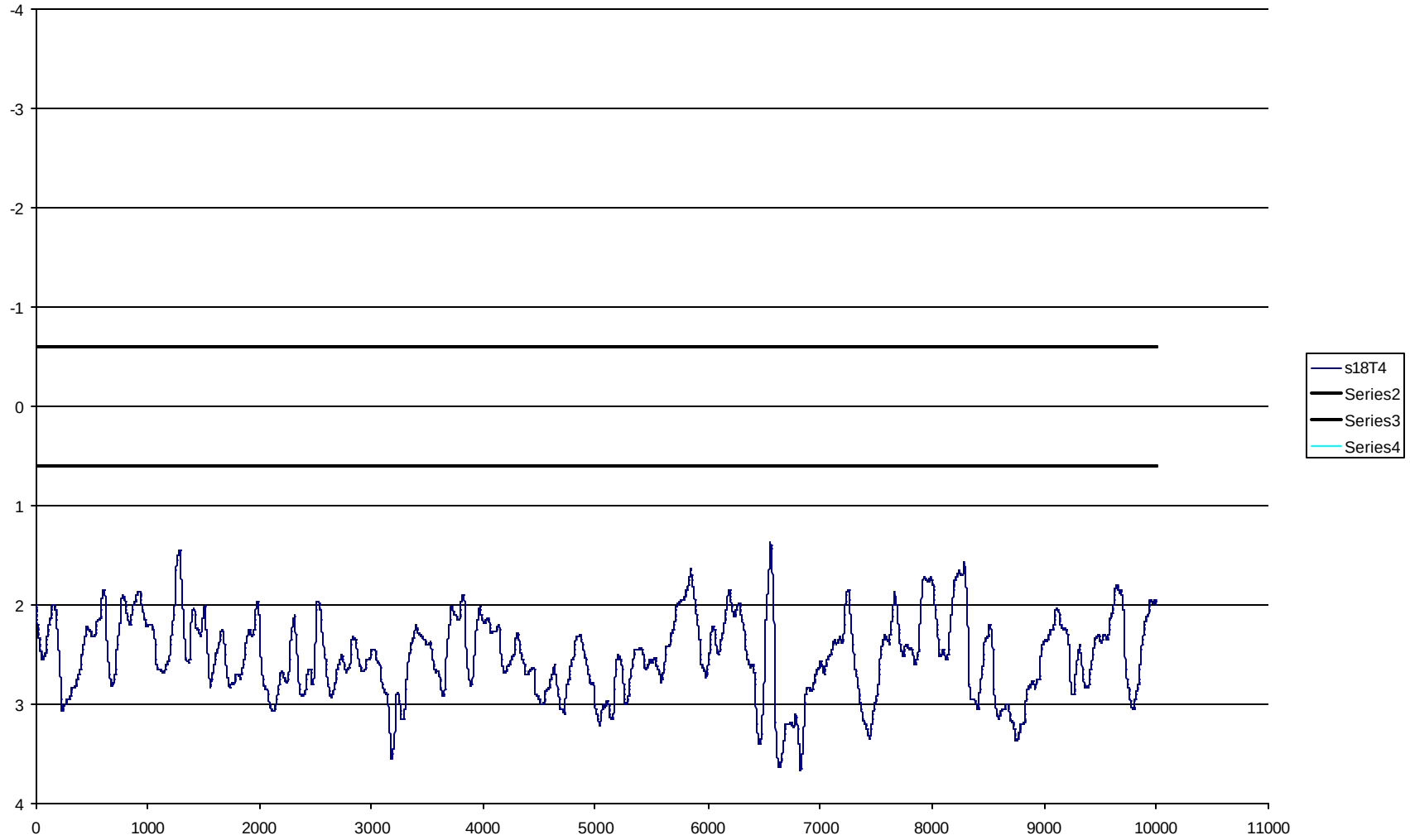

Figure A106: Lane position (in meters relative to center of road) for S18 driving for 10 km under Condition T4.