

JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY



Leveraging Telematics and Weather Data to Study the Productivity of Roadside Mowers



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RECOMMENDED CITATION

Mathew, J. K., Morgan, W. T., Li, H., Downing, W. L., Kraushar, M. S., Wells, T., Krogmeier, J. V., & Bullock, D. M. (2018). *Leveraging telematics and weather data to study the productivity of roadside mowers* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/23). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284316868>

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Print ISBN: 978-1-62260-515-6

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA/IN/JTRP-2018/23	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Leveraging Telematics and Weather Data to Study the Productivity of Roadside Mowers		5. Report Date November 2018	
		6. Performing Organization Code	
7. Author(s) Jijo K. Mathew, William T. Morgan, Howell Li, William L. Downing, Matt S. Kraushar, Timothy Wells, James V. Krogmeier, and Darcy M. Bullock		8. Performing Organization Report No. FHWA/IN/JTRP-2018/23	
9. Performing Organization Name and Address Joint Transportation Research Program (SPR) Hall for Discovery and Learning Research (DLR), Suite 204 207 S. Martin Jischke Drive West Lafayette, IN 47907		10. Work Unit No.	
		11. Contract or Grant No. SPR-4333	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. Enter information not included elsewhere, such as translation of (or by), report supersedes, old edition number, alternate title (e.g. project name), hypertext links to documents or related information in the form of URLs, PURLs (preferred over URLs - https://purl.org/docs/index.html), DOIs (http://www.doi.org), insertion of QR codes, copyright or disclaimer statements, etc. Edit boilerplate FHWA statement above if needed.			
16. Abstract <p>The Indiana Department of Transportation (INDOT) is responsible for the construction and maintenance of approximately 11,000 centerline miles of state roads, US routes and interstates. Mowing operations along the state rights-of-way to manage vegetation consume considerable resources. Mowing activities are usually reported by daily work orders and it is difficult to obtain quantitative information characterizing the utilization and productivity of the mowing operations.</p> <p>This research uses telematics data from commercial sensors to track the daily activity of seven mowers in the Fort Wayne district. Weather data from NOAA was also captured to estimate the weather related delays. During a one-month period, the mowers collectively covered a total of around 1170 miles and an area of nearly 1800 acres of mowing. Crews worked alternative work schedules with extended hours four days a week. On an average 9.5-hour workday approximately 50% of the time is spent actively mowing. The simple telematics based metrics and visualization graphics proposed in this paper can be used by agencies to evaluate the efficiency of their mowing operations to provide guidance on resource allocation, scheduling, and comparison with alternative contract agencies as they provide a concise way of communicating to stakeholders the overall efficiency of the mowing. The proposed utilization graphics may be of particular interest to operations and can be used to identify opportunities for efficiency improvements.</p>			
17. Key Words roadside mowing, productivity, telematics, resource allocation		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 18	22. Price

EXECUTIVE SUMMARY

LEVERAGING TELEMATICS AND WEATHER DATA TO STUDY THE PRODUCTIVITY OF ROADSIDE MOWERS

Introduction

The Indiana Department of Transportation (INDOT) is responsible for the construction and maintenance of approximately 11,000 centerline miles of state roads, US routes, and interstates. Maintenance of roadside vegetation is very important to roadway safety as it provides better sight distance for drivers and prevents development of trees in the clear zone. Mowing operations to manage vegetation along the state rights-of-way consume considerable resources. Mowing activities are usually reported by daily work orders, and it is difficult to obtain quantitative information characterizing the utilization and productivity of the mowing operations. This research uses telematics data from commercial sensors to track the daily activity of seven mowers in the Fort Wayne district. Weather data from the National Oceanic and Atmospheric Administration (NOAA) was also captured to estimate the weather-related delays.

Findings

During a one-month period, the mowers collectively covered a total of approximately 1170 miles and an area of nearly

1800 acres of mowing. Crews worked alternative work schedules with extended hours four days a week. On an average 9.5-hour workday, approximately 50% of the time is spent actively mowing. Other activities such as crew commute and equipment transport accounted for 7% each, whereas customary breaks, such as lunch breaks, accounted for 10%. Weather delays were minimal at nearly 3%. The simple telematics-based metrics and visualization graphics proposed in this study can be used by agencies to provide guidance on resource allocation, scheduling, and comparison with alternative contract mowing. The proposed utilization graphics may be of particular interest to agencies since they provide a concise way of communicating to stakeholders about the overall efficiency of the mowing operations and can also identify opportunities for efficiency improvements.

Implementation

Data was collected during the first cycle of mowing operations, May 29 to June 30, 2018. Commercial GPS trackers provided time-stamped location data at a frequency of 5-second intervals. The built-in accelerometers also ensured that the devices only recorded data when the mowers were in motion. The work hours were characterized into crew commute, equipment transport between locations, mowing, and downtime. Based on preliminary analysis from one week of data, activities with speeds less than 6 mph were assumed to be mowing. Downtime was further classified into delays due to maintenance, customary breaks, and weather related events.

CONTENTS

1. BACKGROUND	1
2. STUDY MOTIVATION AND SCOPE	1
3. EQUIPMENT AND DATA	1
3.1 Mowers	1
3.2 Data	1
4. ANALYSIS	4
4.1 Mowing Mileage and Area	4
4.2 Activity Hours	4
4.3 Characterization of Work Hours	6
4.4 Allocation of Work Hours	8
5. CONCLUSIONS	9
6. ACKNOWLEDGMENTS	9
REFERENCES	9

LIST OF TABLES

Table	Page
Table 3.1 Mowing units	2
Table 4.1 Distance and area covered by the mowers during the one-month study period	5
Table 4.2 Mean percentage allocation of activities during work hours	8

LIST OF FIGURES

Figure	Page
Figure 3.1 GPS equipment installation on tractor	2
Figure 3.2 Web dashboard with GPS trajectories and data	3
Figure 4.1 Mowing and transport mileage for mower #7	4
Figure 4.2 Cumulative mowing mileage and estimated mowing area for mower #7	5
Figure 4.3 Active and idle hours for mower #3 during the study period	5
Figure 4.4 Commute to mowing location from management unit and vice-versa	6
Figure 4.5 Comparison of activity hours and rainfall intensity (in/hr) for mower #3	7
Figure 4.6 Characterization of work hours for mower #3	7
Figure 4.7 Average allocation of work hours	8

1. BACKGROUND

Maintenance of roadside vegetation is very important to roadway safety as it provides better sight distance for drivers and prevents development of trees in the clear zone. The Indiana Department of Transportation (INDOT) spends around \$8 million annually mowing herbaceous vegetation across approximately 60,000 acres of medians and roadsides along Indiana roadways (Gerland, 1993). INDOT operates 2 to 3 mowing cycles per year and incorporates herbicide applications to promote desirable vegetation. Maximizing the efficiency of each mowing cycle can free up resources and potentially save revenue that can be reallocated for other roadway maintenance operations.

The utilization of telematics data has been demonstrated in the literature to improve fleet management and resource allocations (Gerland, 1993; Ma & McCormack, 2010; Thong, Han, & Rahman, 2007). One study has shown that telematics data from aircraft can be useful for implementing real-time fleet tracking that can improve airport operations (Mcnamara, Mott, Bullock, Mcnamara, & Bullock, 2016). Research has also been conducted in the agriculture and forestry industries using similar data sources to estimate the operational efficiencies of harvesting equipment (Odhiambo, 2010). Robust methodologies to determine number of passes over terrain and area covered from telematics data are well established in the literature (Taylor, McDonald, Veal, & Grift, 2001). However, very little has been discussed on the productivity and efficiency of roadside mowing operations. Gendek, Zychowicz, and Powierza (2012) used GPS data to determine the productivity of mowers for mowing early successional vegetation in forested environment and possible ways to increase productivity. Results from this study revealed that approximately 52% of the working time was spent for mowing while commute (14%), standstills (28%), breaks (2.4%) and others made up the remaining time. Equipment loading and unloading was one of the major causes of delay (Gendek et al., 2012). Gendek et al. did not provide significant analysis of factors that impacted efficiencies. Herold, Lowe, and Dukes compared herbicide and mowing treatments at six sites throughout Indiana and found that mowing was less effective and more expensive than herbicide treatments (2013). The study also highlighted an INDOT management report from 2010, according to which mowing only covers around 18.5 miles/day.

Apart from roadside mowing, some of the major activities during mowing operations include crew commute, equipment transport between locations, and

maintenance. With the current reporting structure, these types of activities are difficult to track.

2. STUDY MOTIVATION AND SCOPE

This paper proposes various performance metrics that track mowing, non-mowing transport, severe weather, commute time, and maintenance activities using telematics and weather data.

This research uses telematics data from commercial sensors to track the daily activity of seven mowers in the region adjacent to Fort Wayne, IN. Weather data from National Oceanic and Atmospheric Administration (NOAA) is also captured to estimate the weather related delays. The simple telematics based metrics proposed in this paper can be used by agencies to evaluate the efficiency of their mowing operations to provide guidance on resource allocation, scheduling, and comparison with alternative contract mowing.

3. EQUIPMENT AND DATA

3.1 Mowers

Table 3.1 shows the seven mower combinations across four units deployed in the Bluffton sub-district of Fort Wayne, IN during the first cycle of mowing. This mowing cycle began on May 29, 2018, and ended on June 28, 2018. Figure 3.1a shows a tractor with 15' flex-wing rotary mower and battery powered telematics (Figure 3.1b).

3.2 Data

Data collection was carried out during the mowing cycle using commercial GPS devices which provide probe vehicle location data at a frequency of 5-second intervals. In-built accelerometers also ensured that the devices only recorded data when the mower was in motion. The devices, installed behind the driver seat (Figure 3.1b), also reported waypoint data in real time through a web service, hosted by the commercial provider (Figure 3.2a). The data, available for download in a comma separated value (CSV) format, included time-stamped latitude and longitude with a precision of six decimal points (36'), speed, heading and a battery status indicator (Figure 3.2b). In total, there were around 450,000 data points from the seven mowers during the study period. The data was stored in a relational database (Microsoft SQL Server) and analyzed using R, an open source software environment for statistical computing and graphics. After importing the data from the SQL server, custom scripts were formulated in R to analyze the data and develop the plots.

TABLE 3.1
Mowing units

Mower #	Make	Model	Year	Description	Unit Name
1	Bushwhacker	ST-150	2006	15' Flex-Wing Rotary Cutter	Center of 69
2	Woods	BW1800X	2017	15' Flex-Wing Rotary Cutter	Unit 261
3	Woods	BW1800X	2017	15' Flex-Wing Rotary Cutter	
4	Alamo	EAGLE 15	2005	15' Flex-Wing Rotary Cutter	
5	Bushwhacker	7210	2008	6' 3-Point Rotary Cutter	Unit 3
6	Schulte	S-150	2003	15' Flex-Wing Rotary Cutter	Unit 4
7	Bushwhacker	ST-180	2006	15' Flex-Wing Rotary Cutter	

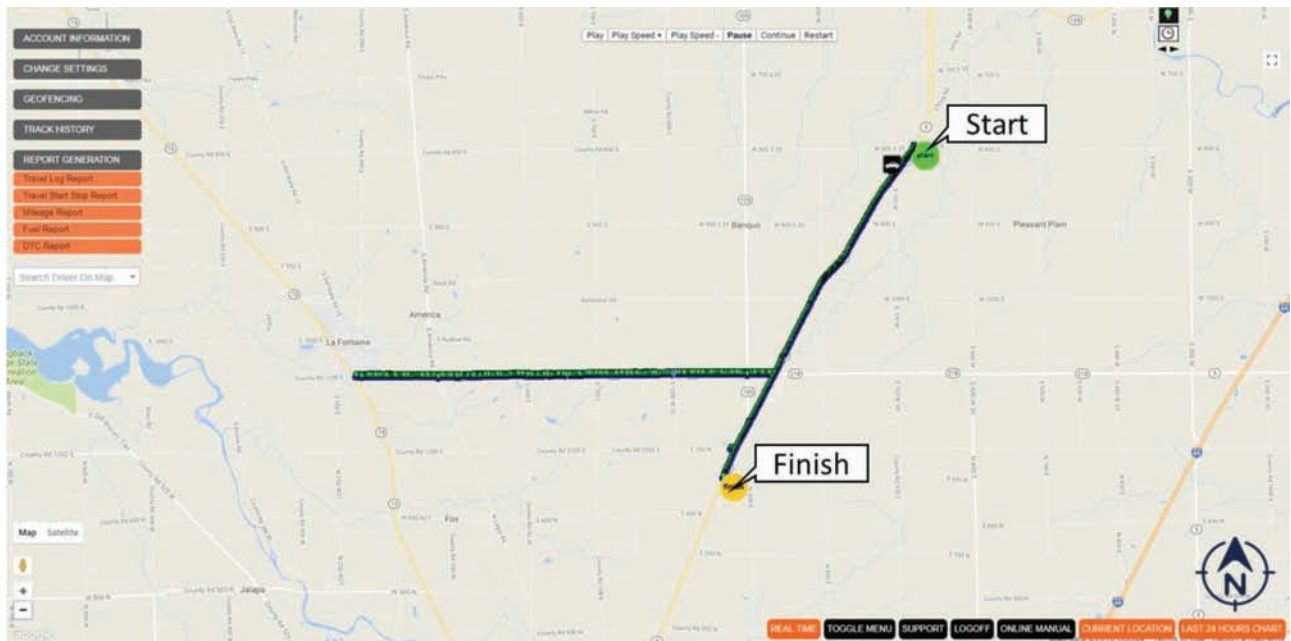


(a) Tractor with 15' flex-wing rotary mower



(b) Installation of GPS device on the mesh behind driver seat

Figure 3.1 GPS equipment installation on tractor.



(a) Web dashboard with GPS trajectory of a day's mowing activity



(b) Zoomed-in view of the trajectories with data provided by the vendor

Figure 3.2 Web dashboard with GPS trajectories and data.

4. ANALYSIS

A typical mowing day consists of four main activities:

1. **Commute:** Crew commutes from the office to the mowing location where the equipment is parked between shifts by way of crew cab pickup.
2. **Transport:** Crews are often tasked with mowing different routes. After the completion of a particular area, they might need to transport the equipment to another location. Similarly, an area may already be maintained by an adjacent landowner, or the route may transverse through a town. This in-use/operational time was isolated from that of mowing based on speeds identified exceeding 6 miles per hour (mph) for a period of one week.
3. **Mowing:** The activity of mowing the right-of-way. This is identified as the in-use/operational time when the mowers were traveling at speeds less than 6 mph.
4. **Downtime:** Period where the mower is not moving. This could be due to equipment maintenance, work breaks such as lunch, or delays due to weather related events.

4.1 Mowing Mileage and Area

The distance between consecutive geo-stamped points was approximated using the Haversine formula (Sinnott, 1984). The Haversine formula uses the latitude and longitude to compute the minimum distance between any points on the Earth's surface, given by

$$d = 2r \sin^{-1} \left(\sqrt{\sin^2 \left(\frac{\phi_2 - \phi_1}{2} \right) + \cos(\phi_1) \cos(\phi_2) \sin^2 \left(\frac{\psi_2 - \psi_1}{2} \right)} \right)$$

where d is the distance between two points with longitude and latitude (ψ, ϕ) and r is the radius of the Earth (approximately 3963 miles).

Figure 4.1 shows the daily mowing and transport miles covered by mower #7 during the study period. For most of the days, the distance covered by mowing was more than the transport distance. On average, the total daily distance covered by a mower was found

to be around 21 mi (13 mi of mowing and 8 mi of transport).

The mowing area was estimated using the width of the mower and the distance mowed, given by

$$\text{Area (in acres)} = \frac{\text{Mower Width (ft)} \times 0.90 \times \text{Distance Mowed (mi)} \times \frac{5280 \text{ ft}}{\text{mi}}}{43,560 \frac{\text{sq.ft}}{\text{acre}}}$$

A factor of 0.90 is assumed to account for the mower width lost due to the overlap of previous passes (Shinners, Digman, & Panuska, 2012). Figure 4.2 shows the cumulative mowing mileage and area covered by mower #7. Table 4.1 provides an overview of the total distance and area covered by all the mowers during the study period. Over the one-month period, the mowers collectively covered a total of around 1170 miles and an area of nearly 1800 acres of mowing. The GPS device on mower #6 had some data loss due to limited cellular coverage, thus resulting in lower reported miles.

4.2 Activity Hours

All maintenance activities are reported internally for time keeping/payroll purposes by the total work hours for a day for a given maintenance work activity that the crew works on. Using mowing as an example activity, the crew would record 9.5 hours of a 9.5 hour work day as "mowing." Without better insights on the activity periods, it is difficult to estimate the productivity of the mowing operations.

Figure 4.3 shows the active periods reported by mower #3 during the study period. The built-in accelerometers on the GPS devices ensured that data was only captured during the active periods. The black bars represent the active periods on a day, which include both mowing and transport. The minimum threshold for inactive periods was assumed as 10 minutes to

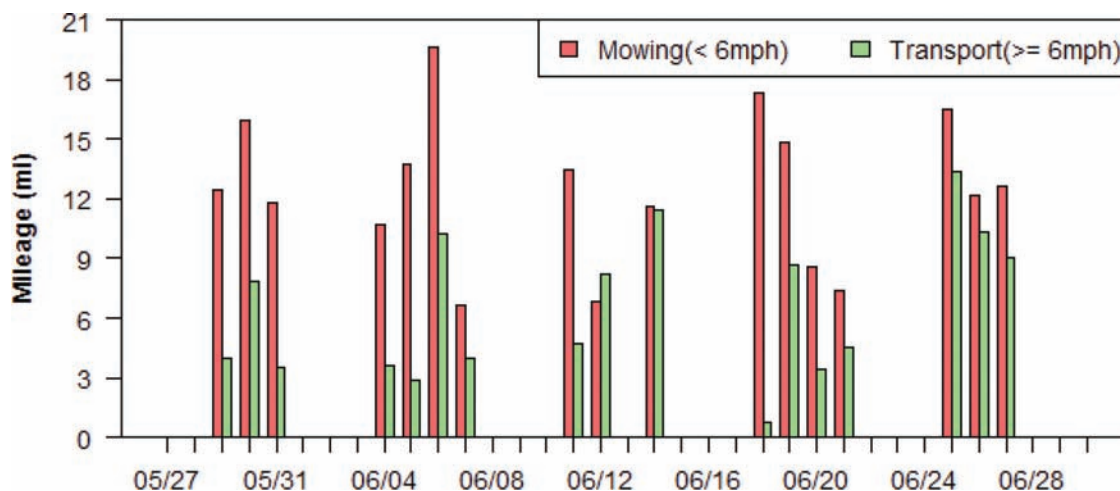


Figure 4.1 Mowing and transport mileage for mower #7.

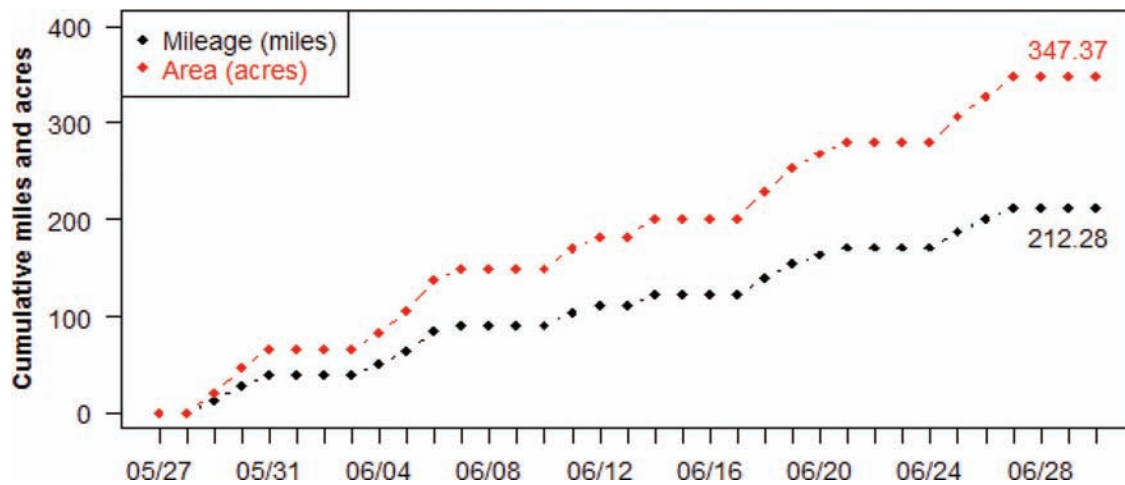


Figure 4.2 Cumulative mowing mileage and estimated mowing area for mower #7.

TABLE 4.1
Distance and area covered by the mowers during the one-month study period

Mower #	Mower Width (ft)	Distance (miles)			Mowing Area (acres)
		Mowing	Transport	Total	
1	15	147.30	171.07	318.37	241.04
2	15	224.30	147.25	371.55	367.04
3	15	236.30	152.31	388.61	386.67
4	15	161.50	46.60	208.10	264.27
5	6	122.31	143.30	265.61	80.06
6*	15	67.49	30.10	97.59	110.44
7	15	212.28	110.71	322.99	347.37
Total		1171.48	801.34	1972.82	1796.88

*Mower #6 had data loss due to limited cellular coverage.

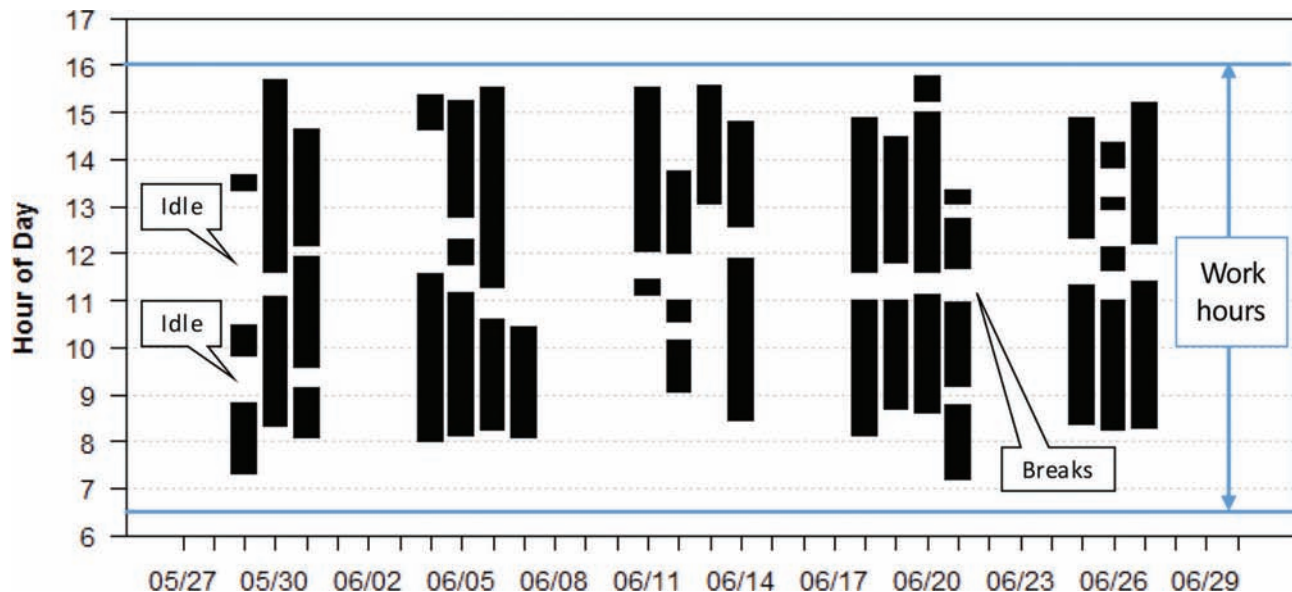


Figure 4.3 Active and idle hours for mower #3 during the study period.

account for short-term activities such as allowing for traffic to pass or moving traffic warning signs. The inactive periods are considered any combination of the following:

4.2.1 Commute

As mentioned earlier, crews spend both their early and final parts of the day commuting to and from the



Figure 4.4 Commute to mowing location from management unit and vice-versa.

mowing location. Figure 4.4 demonstrates the commute on a particular day from the management unit office to the mowing location. The management unit for the crew cab pickup is identified from the daily work orders. For each day, an approximate commute time is then estimated from Google Maps, using the management unit and mowing location as origin and destination, respectively. Similarly, the commute time after work is also added to attain the total commute time for a day.

4.2.2 Breaks

Generally, a work crew is allotted time for three breaks—this commonly is experienced as a 30-minute lunch and two 15-minute breaks (one pre- and post-lunch), for example these lunch breaks can be identified around the 11AM period in Figure 4.3.

4.2.3 Weather

Weather related events, especially rain, could also impact the mowing operations. To gain more insights on such delays, weather data provided by the National Oceanic and Atmospheric Administration (NOAA) and the National Weather Service was also analyzed (Baldwin, Snyder, Miller, & Hoogewind, 2015). This data, integrates observations from weather stations, local radar and other available models including the North America Land Data Assimilation System (NLDAS) (Land Data Assimilation System, 2018) to record weather variables on an hourly basis for a spatial grid of roughly 8 square miles (McNamara, Sakhare, Li, Baldwin, & Bullock, 2017).

The weather data for a particular hour was aggregated from the weather grids along the mower trajectory during that hour. Figure 4.5 compares the activity hours clocked by mower #3 with the rainfall data (color-coded by intensity (in/hr)). The mowers were generally idle during rainfall periods. For example, on June 21 and June 26, work was delayed due to moderate rainfall (callout i). There were also periods where work resumed during periods identified by Doppler as light rainfall. This is evident on June 20 (callout ii), where the mowers were only inactive for 30 minutes during the 2-hour rainfall period from 2 to 4 pm. These inactive periods due to weather events were recorded as weather delays.

4.2.4 Maintenance

Equipment maintenance can also result in idle periods. Fueling is performed every morning whereas removal of debris from mower decks and cleaning of radiators are carried out at end of the day. Greasing is done every other day while blades are changed once in a week. Major maintenance issues such as flat tires and failures of power take off (PTO) shafts can also lead to extended inactivity as experienced on May 29 as can be seen in 4.6 The crews usually report major maintenance activities on the day cards.

4.3 Characterization of Work Hours

Figure 4.6 compares the reported work hours with the breakdown of activities during all days for mower #3. The reported work hours (gray bars) are obtained from the daily work orders. Crews follow a four days per week work schedule, with 9.5 hours on three days

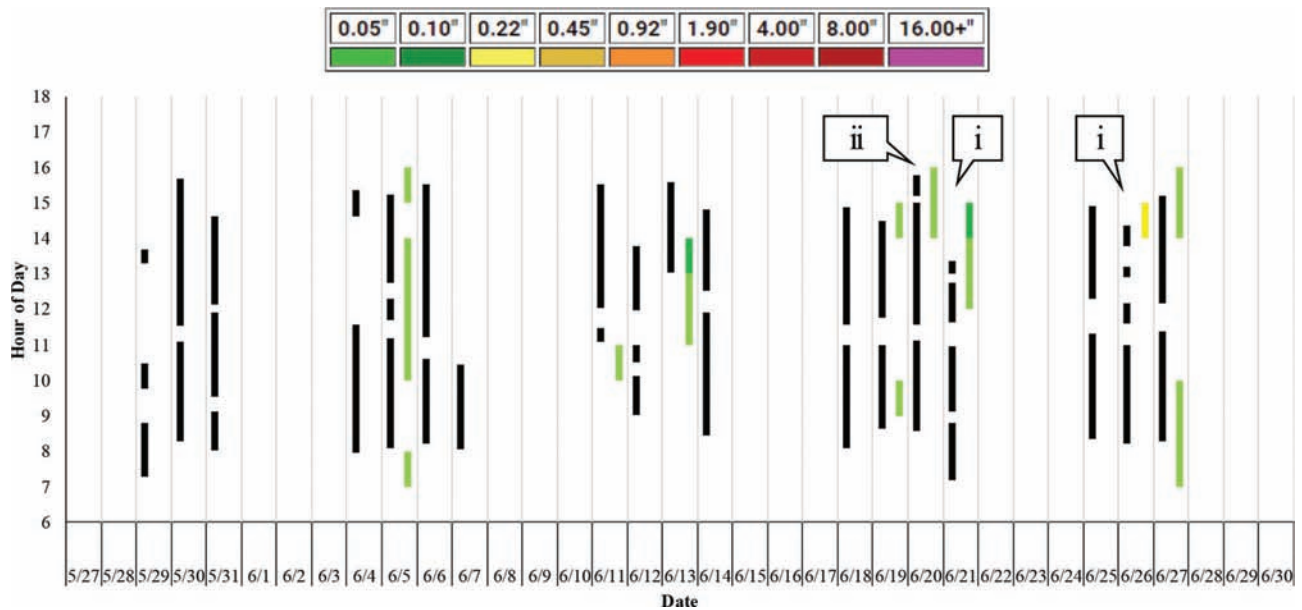


Figure 4.5 Comparison of activity hours and rainfall intensity (in/hr) for mower #3.

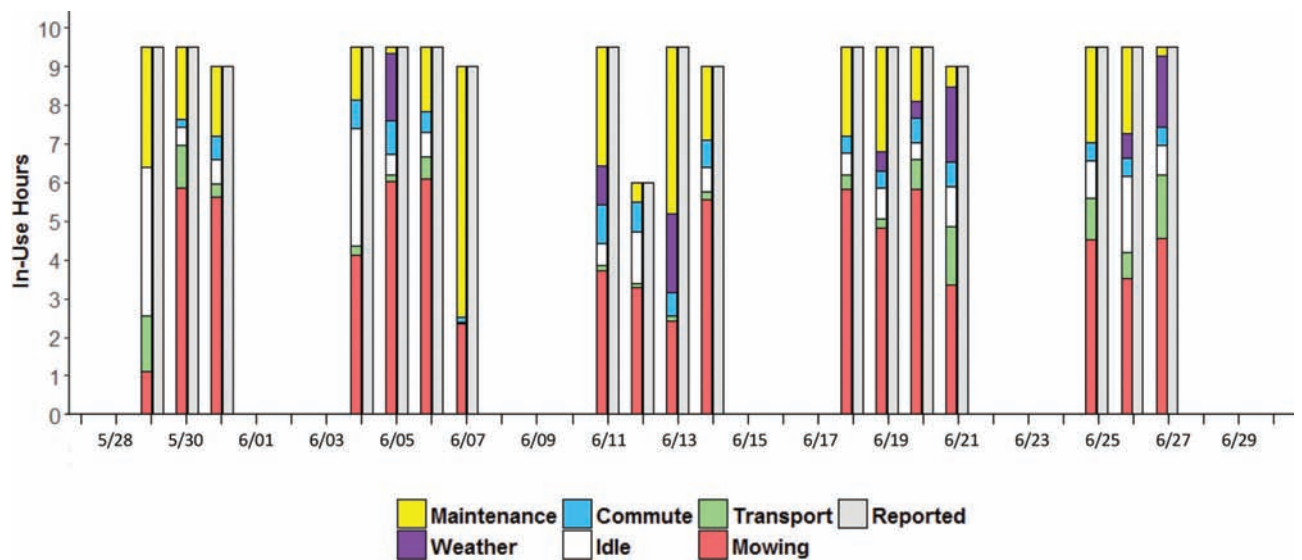


Figure 4.6 Characterization of work hours for mower #3.

and 9 hours on the fourth day. The active periods in Figure 4.3 are further characterized by the mowing and transport periods, denoted by the red and green bars, respectively, in Figure 4.6. The blue bar represents commute time while the purple bars denote the inactive periods due to weather (from Figure 4.5).

The white bars denote the idle period which is defined as the inactive periods between the first and final active period of the day. For example, in Figure 4.3, there are two idle periods on May 29; together they result in a 3.5 hour inactive period shown by the white bar in Figure 4.6. The remaining portion of a day is assumed to be maintenance, shown by the yellow bars. Although the idle bars mostly represent the breaks,

inactivity during these periods could also be caused by maintenance. Validating with day cards, it was found that this was indeed a day with known mechanical issues, with crews reporting a flat tire. However, with the current day card reporting system, it is difficult to identify the exact duration of maintenance.

In Figure 4.6, June 6 depicts a highly productive day with more than six hours of mowing and very little idle time. Over the mowing cycle, transport periods were higher during the first and last day of mowing, as the crews transport the equipment to the field from the management unit and back, respectively. This characterization of the work hours provides better insights on the various activities and

TABLE 4.2
Mean percentage allocation of activities during work hours

Mower#	Mowing (%)		Transport (%)		Idle (%)		Commute (%)		Weather (%)		Maintenance (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	46.7	16.5	10.3	4.9	8.9	6.7	6.5	4.5	2.7	4.4	24.9	21.57
2	44.6	18.0	6.3	5.9	11.4	11.9	5.9	2.3	3.8	6.5	27.9	21.6
3	47.7	15.5	6.3	5.6	11.2	10.8	5.9	3.1	5.9	8.4	22.9	16.6
4	50.3	15.5	3.7	3.1	5.8	2.8	6.9	2.4	2.5	6.0	30.8	19.5
5	45.9	12.2	7.6	5.4	11.4	7.9	8.9	5.5	2.1	5.1	24.1	16.4
6	32.6	21.4	3.7	2.7	7.3	5.1	9.0	1.5	2.1	6.0	45.2	30.1
7	49	13.5	5.9	3.2	10.64	6.1	8.4	2.0	1.0	3.8	25.1	16.7
Average	47.4	2.1	6.7	2.2	9.9	2.2	7.1	1.3	3	1.7	25.9	2.9

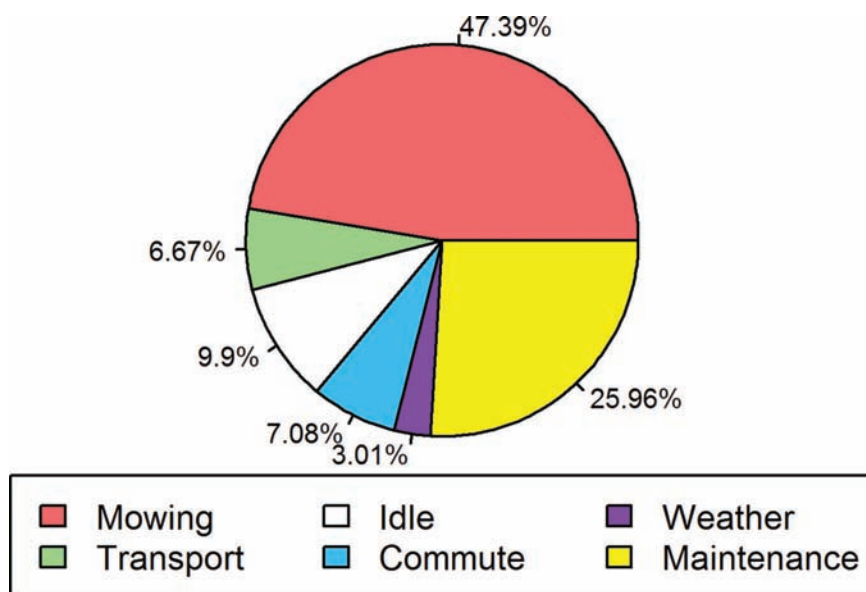


Figure 4.7 Average allocation of work hours.

helps identify opportunities for improving the productivity of the mowing operations.

4.4 Allocation of Work Hours

Table 4.2 shows the mean percentage allocation of work hours and their standard deviation for all mowers during the one-month study period. The percentage time for mowing varied between 44.6% (excluding mower #6 due to data loss) and 50.3%, with mower #4 recording the highest. Mower #1 had the greatest transport time, nearly 10% of the total work hours. This unit covered the center of I-69 area, which was the farthest among all the areas from the management unit (around 170 miles of transport distance). The high standard deviations (SD) for mowing and maintenance indicates the high fluctuations for time spent on these activities throughout the period.

Figure 4.7 shows the average percentage allocation of work hours across all mowers, excluding mower #6. Results show that the crews productivity (approximately 50%, at 95% confidence interval and standard

deviation of 2.08) were consistent with those reported by Gendek et. al. (2012). On an average 9.5 hour work-day, a combined total of 14% (nearly 1.5 hours) was spent for crew commute and equipment transport. The mowers were idle for nearly 10% of the time, which is roughly an hour; the total time allotted for lunch and other breaks. The remaining 25% or 2.5 hours are assumed to be downtime due to equipment maintenance. It is to be noted that, other activity could also contribute towards this downtime. However, with the current reporting structure, we were unable to identify the major contributing factors of this downtime, apart from equipment maintenance. The overall delays due to weather was found to be minimal, since weather-related events were not very frequent during our study period.

The results provided in this study can be used to identify the utilization of the various activities during roadside mowing operations. Systematically tracking daily operations with high downtime may be an impetus to examine operational strategies and opportunities to improve the mowing operations. With the ultimate goal of increasing the mowing production, one operational

strategy would be to set operational targets. For example, allocating a maximum of 1 hour (10%) for equipment maintenance, can readily improve the efficiency of both the equipment and mowing operations. Having a mechanic truck and a two person crew on-site prior to the arrival of the mowing crew could also decrease time spent on maintenance. Better outfitted fuel trucks for fast fill-ups could also be a worth-while investment to reduce downtime associated with fueling. Additionally, the introduction of a detailed maintenance reporting system can also provide better insights on the downtime period. Such a robust reporting system will also help agencies to identify specific opportunities for improving management practices and resource allocations.

5. CONCLUSIONS

This research uses telematics data from seven mowers in the district of Fort Wayne, IN to characterize the utilization of various activities during the mowing operations. Data was collected during the first cycle of mowing operations, 29 May to 30 June 2018. Commercial GPS sensors with in-built accelerometers provided time-stamped location data when the mowers were active. Weather data from NOAA was also captured to estimate the weather related delays. During the one-month period, the mowers collectively covered a total of around 1170 miles and an area of nearly 1800 acres of mowing. Crews worked alternative work schedules with extended hours four days a week. On an average 9.5 hour work day approximately 50% of the time was spent for mowing. Other activities such as crew commute and equipment transport accounted for 7% each, whereas customary breaks, such as lunch breaks, accounted for 10%. Weather delay was minimal with nearly 3%. Downtime due to maintenance was estimated to be around 26%.

The analysis and graphics developed in this study (Figure 4.3, Figure 4.6, Figure 4.7 and Table 4.2) can be used to identify opportunities for enhancing management practices and resource allocations of roadside mowing operations. Operational strategies to reduce the maintenance and transport activities can result in improved mowing efficiencies. Detailed maintenance reporting systems could also provide better insights on the downtime. The ease of data collection and analysis show the potential for these techniques to be extended to track the productivity of other maintenance operations as well.

6. ACKNOWLEDGMENTS

This work was supported by the Joint Transportation Research Program administered by the Indiana Department of Transportation (INDOT) and Purdue University. The authors would like to thank Tom Dull and Roy Piercy from INDOT for their technical support throughout the data collection. The contents of this paper reflect the views of the authors, who are

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About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1 — evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: <http://docs.lib.purdue.edu/jtrp>

Further information about JTRP and its current research program is available at: <http://www.purdue.edu/jtrp>

About This Report

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The recommended citation for this publication is:

Mathew, J. K., Morgan, W. T., Li, H., Downing, W. L., Kraushar, M. S., Wells, T., Krogmeier, J. V., & Bullock, D. M. (2018). *Leveraging telematics and weather data to study the productivity of road-side mowers* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/23). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284316868>