Potential Factors Affecting Roadway Departure Crashes in Oahu, Hawaii

Authors: Mohammadreza Hashemi (Lead Author) [1], Adrian Ricardo Archilla [2]

[1] Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Hawaii at Manoa

Email:
hashemi@hawaii.edu
Mailing Address:
Department of Civil and Environmental Engineering,
University of Hawaii at Manoa
2540 Dole Street, Holmes 102,
Honolulu, Hawaii 96822 USA
Telephone Number:
+1 (808) 859-7122
ITE Student Membership number:
1056237

[2] Associate Professor, Department of Civil and Environmental Engineering, University of Hawaii at Manoa

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Abstract

According to the Federal Highway Administration (FHWA), roadway departure (RwD) crashes account for approximately 56% of highway fatalities in the United States. Therefore, investigating the characteristics of RwD crashes is an indispensable move towards fulfilling the vision of zero deaths and serious injuries. This study uses data from Oahu extracted from Hawaii police crash reports for 4 consecutive years (2008-2011) to examine, using GIS tools, the spatial distribution of RwD crashes and their contributing factors by using maps extracted at the district level. The paper initially explores crashes by locality and types of collision, then it investigates how roadway design, human, and environmental factors lead to RwD crashes *using the Bayesian Statistical Approach*. The results reveal the most common circumstances under which RwD crashes occur. On the other hand, the paper demonstrates that the north central district of Oahu have a higher rate of RwD crashes possibly because of the more winding nature of the roads in that district. At the same time, the crashes in the north central district are more severe in comparison to other districts possibly because of type on collision (Head on) since most of RwD crashes have occurred on two-way undivided roads. These results can pave the way for future research on RwD crashes and provide a better understanding of the spatial distribution of RwD crashes to help decision makers to invest effectively on RwD systemic safety plan.

Keywords: Roadway departure crashes, Roads safety, spatial distribution, Crash severity, Road design

1. Introduction

Highway fatalities and injuries in the United States continue to be a major national safety issue. While injuries are a concern, safety performance is typically expressed in terms of fatalities and fatal crashes because more extensive data are available for these crashes. Although there has been a downward trend in both the fatal crash rates and number of deaths on highways, the fact that there are still 34,674 average annual fatalities (2007-2014) indicates that much work still needs to be done. According to FHWA, RwD crashes account for 56% of these fatalities. Likewise, the statistics in the State of Hawaii follow the same trend with an average of 54% of all traffic fatalities accounted for by those occurring on RwD crashes*(1)*.

FHWA published a strategic plan for RwD crashes and defines a RwD crash as: *A non-intersection crash in which a vehicle crosses an edge line, a centerline, or otherwise leaves the traveled way(1)*. Therefore, RwD crashes includes both run-off-road (ROR) and head-on crashes. ROR crashes involve vehicles that leave the travel lane and encroach onto the shoulder and beyond and hit one or more of any number of natural or artificial objects, such as bridge walls, poles, embankments, guardrails, parked vehicles, and trees*(2)*. A head-on crash typically occurs when a vehicle crosses a centerline or a median and crashes into an approaching vehicle. Head-on crashes occur as a result of a driver's inadvertent actions—as with run-off-road (ROR) encroachments or deliberate actions e.g., executing a passing maneuver on a two-lane road*(3)*.

Diverse methods have been established to develop safety performance functions (SPF) to predict total number of accidents by considering regression-to-mean bias in accident data*(4)*, but development of SPF for RwD crashes has received much less attention. The first step toward estimation of RwD crashes is to identify the contributing factors. A study investigated the relationship between single vehicle ROR crashes and the geometric characteristics of rural two lane roads, and it found that crash frequency and severity will increase when there is a decrease in lateral clearance or shoulder width*(5)*. Another study using data pertaining only to fatal single-vehicle ROR crashes identified the roadway, driver, environment, and vehicle-related factors associated with fatal single-vehicle ROR crashes*(6)*. Other research studies found correlation between ROR crashes severity with factors such as alcohol, drugs, curves ,grades, female

victims, overturn/rollover crashes, and dry roadway surfaces*(7)*. Less information is found in the literature about RwD crashes in detail and identifying common circumstances in which RwD crashes occur.

Moreover, previous research studies on crashes in Hawaii have focused mostly on the role of land use and spatial distribution of sociodemographic characteristics in Oahu[1]. For instance, spatial patterns of crashes were analyzed in Oahu to describe the degree of spatial concentration, to conclude that it fluctuates dynamically, as a response to changing traffic patterns*(8)*. Furthermore, the interplay between demographic, land use, roadway accessibility variables and types of crashes were analyzed in Oahu. The results indicate that demographic variables such as job count and number of people living below the poverty level are significantly associated with injury crashes and pedestrian and bike crashes*(9)*. However, roadway design, human, and environmental factors have not been addressed in previous studies regarding crashes in Oahu.

This research examines the spatial distribution of RwD crashes and contributing factors in Oahu, Hawaii. It explores RwD crashes at the district level from different perspectives such as roadway design, human, and environmental factors to help implementing roadway safety strategies more effectively. In the next section, the data collection process and methodology are described. Section 3 discusses the data analysis results, and the last section presents the conclusions.

2. Data Collection and Methodology

In this study, the State of Hawaii motor vehicle accident reports are used to analyze the statistics of RwD crashes in Oahu for four consecutive years (2008-2011). These reports include general information about the crashes, the motor vehicles and all people were involved in the Crashes.

In addition, use is made of the State of Hawaii office of planning *(10)* and the Honolulu land information systems websites to obtain various GIS shapefiles such as :coastline, roads, zoning, police districts, and state roads *(11)*. The Honolulu police districts' map and related land use information were obtained from the Honolulu police department *(12)*. Figure 1 presents the map of Oahu and the area that is covered by each police district. It also depicts the distribution of population and selected land uses in each district[2]. Table 1 presents the land use and roads information at each district extracted by GIS techniques such as merging, clipping and union.

After detailed examination of police report forms, actions contributing to RwD crashes are identified. However, actions are not enough to categorize a crash as a RwD crash since some other circumstances should also be satisfied according to the RwD crash definition by FHWA. Therefore, the RwD crash data were extracted using the following steps:

Step 1: Filtering for each accident actions related to RwD crashes. This means that at least one RwD action should have occurred in a crash to be considered as a RwD crash.
Step 2: Filtering the location of crashes to non-intersection locations.
Step 3: Excluding the intersection related accidents.

Subsequently, RwD crashes are analyzed in four aspects: characteristic of RwD crashes by locality and type of collision, roadway design factors, human and environmental factors. Results are retrieved based on refined database output, and are presented using GIS tools.

[1] This paper uses Oahu and Honolulu interchangeably, and both refer to the Island of Oahu.
[2] This research excludes green areas, since a large portion of land in Oahu is covered by natural restricted preservation and agricultural fields.

Finally, the approach of Bayesian statistics is used to recognize the predominance of crash-related factors such as roadway design, human and environmental factors in probability of occurrence RwD crashes *(13)*.

$$P(RwD|C_i) = \frac{P(RwD) * P(X_i|RwD)}{P(C_i)} \qquad \textit{Eq.1}$$

$P(RwD|C_i) = Probability\ of\ occurance\ RwD\ crashes\ if\ classifed\ as\ crashes\ class\ i$

$P(X_i|RwD) = Probability\ of\ occurance\ crashes\ class\ i\ if\ classifed\ as\ RwD\ crashes$

$P(RwD) = Probability\ of\ occurance\ RwD\ crashes$

$P(C_i) = Probability\ of\ occurance\ crashes\ type\ i$

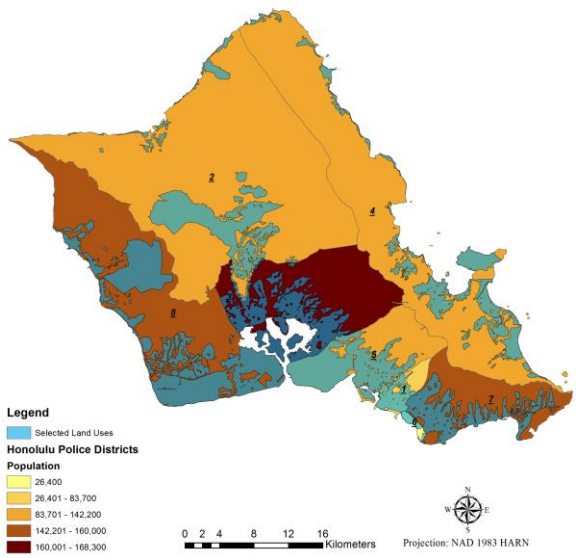


Figure 1 Distribution of population and selected land uses in Oahu, Hawaii

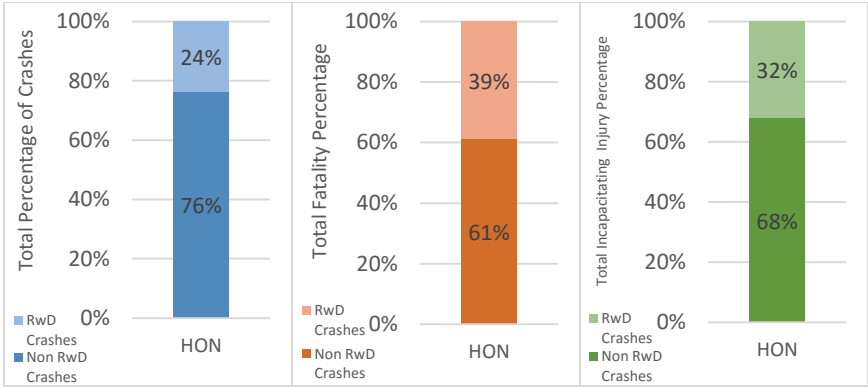
Table 1 Land use and Roads information in Oahu,Hawaii

	Population	Total Acreage Of Selected Land uses	Total Length of Streets(ft.)	Total Length of State Roads(ft.)
District 1	83,700	2,673	592,516	67,702
District 2	117,900	17,395	2,594,291	307,009
District 3	168,300	14,440	2,196,259	350,723
District 4	137,200	13,709	2,319,427	381,442
District 5	142,200	13,349	1,810,411	261,236
District 6	26,400	595	125,713	6,775
District 7	160,000	10,012	1,663,752	97,994
District 8	156,100	28,274	2,640,864	310,166

3. Results

3.1. Characteristics of RwD Crashes in Oahu

The analysis of the total number of motor vehicle fatalities and the total number of fatalities in RwD crashes based on the Fatality Analysis Reporting System (FARS) database shows that RwD crashes follow a downward trend similar to all crashes at both the national level and the state level. While a considerable percentage of total fatalities is related to RwD crashes, it is necessary to investigate the contributing factors in detail. Oahu had total number of 19,685 crashes, 208 fatalities, 780 incapacitating injuries and 16,073 injuries in four years (2008-2011). Figure 2 presents crashes statistics in Oahu.



(a) *(b)* *(c)*

Figure 2 Crash Statistics a) Total number of Crashes b) Total Number of Fatalities c) Total Number of Incapacitating Injuries

Figure 3 compares the spatial distributions of total crashes and total RwD crashes. Table 2 shows that total number of crashes are correlated with population, and total number of RwD crashes are correlated with population, total acreage of selected land uses, cumulative length of roads and state roads in each district.

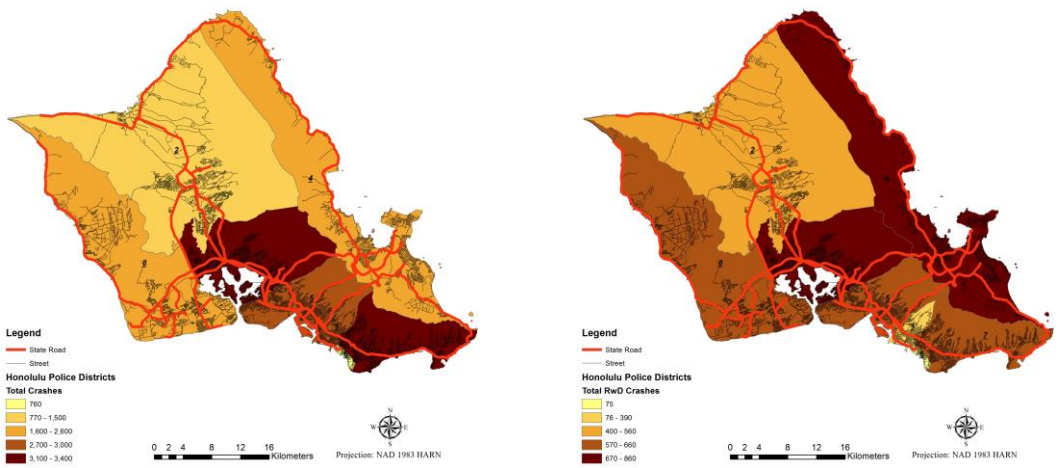


Figure 3 Spatial Distribution of Total Crashes V.S. RwD Crashes

Table 2 Correlation between total number of crashes, Land use, and Roads Data

	Population	Total Acreage Of Selected Land uses	Total Length of Streets(ft.)	Total Length of State Roads(ft.)
Total Number of Crashes	0.72	0.12	0.25	0.21
Total Number of RwD Crashes	0.92	0.65	0.84	0.85

3.1.1. Distribution of the Roadway Departure Crashes by Locality

According to table 3, in spite of the fact that 48.32% of all crashes are RwD crashes on state roads, they account for 67.90% of fatalities. This indicates that state roads crashes are more severe. Furthermore, unlike in other states, 87.78% of all RwD crashes occurred in urban area since Oahu is a small island and roads are located in large part in urban areas[3]*(14)*. Figure 4 depicts that the north central district has a higher rate of RwD crashes, and consequently higher rate of fatalities, incapacitating injuries,

[3] For instance 32% of RwD crashes occurred in urban area in Oregon.

and injuries. District 4 has the same situation, essentially these two districts have approximately the same total length of state roads.

Table 3 Roadway Departure Crashes , Fatalities and Injuries by Locality (2008-2011)

	Crashes		Fatalities		Injuries	
Locality	**Total**	**Percentage**	**Total**	**Percentage**	**Total**	**Percentage**
County Road	**2412**	**51.68%**	**26**	**32.10%**	**1402**	**43.64%**
Rural	158	3.39%	8	9.88%	131	4.08%
Urban	2254	48.30%	18	22.22%	1271	39.56%
State Road	**2255**	**48.32%**	**55**	**67.90%**	**1811**	**56.36%**
Rural	413	8.85%	8	9.88%	316	9.84%
Urban	1842	39.47%	47	58.02%	1495	46.53%
Grand Total	**4667**	**100.00%**	**81**	**100.00%**	**3213**	**100.00%**

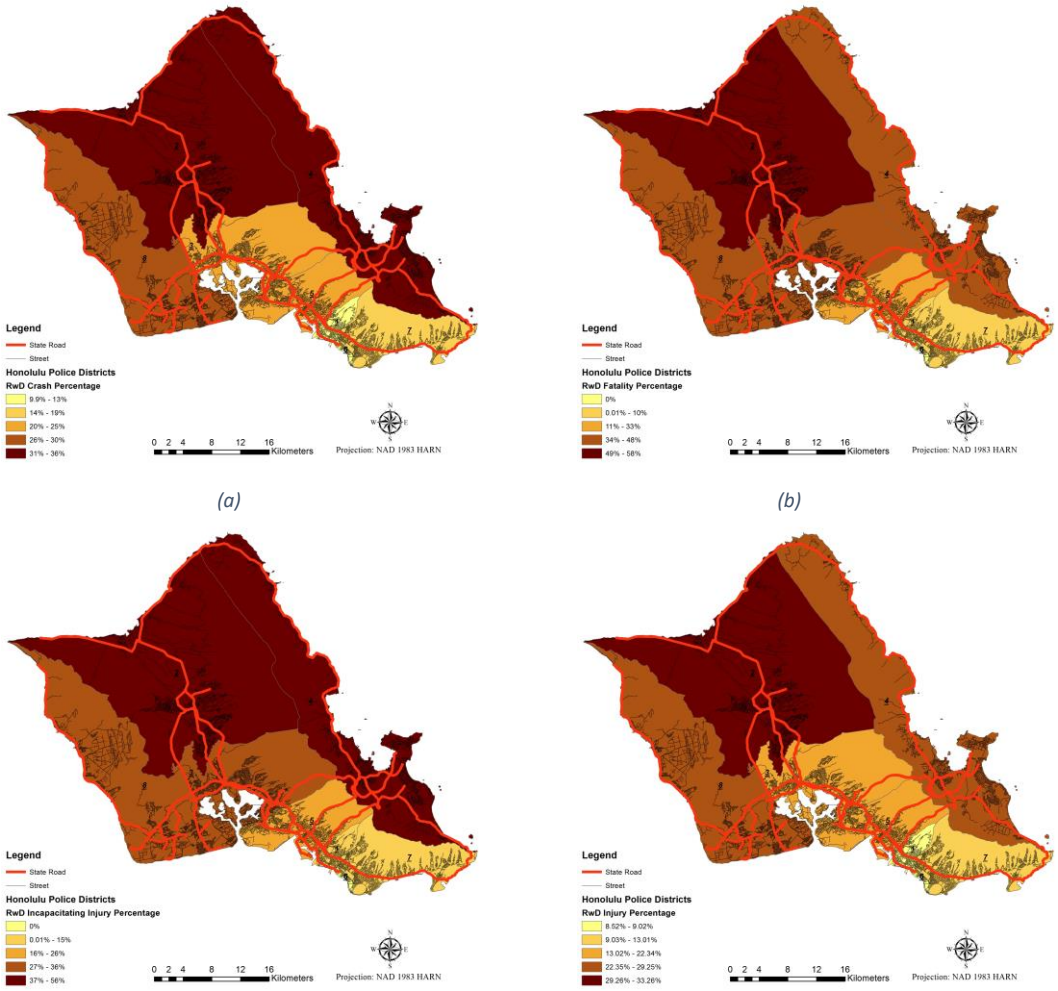


Figure 4 Spatial Distribution of RwD Crashes to All Crashes a) Percentage of Total Number of RwD Crashes to All Crashes b) Percentage of RwD Crashes Fatalities to All Fatalities c) Percentage of RwD Crashes Incapacitating Injuries to All Incapacitating Injuries d) Percentage of RwD Crashes Injuries to All Crashes Injuries

3.1.2. Roadway Departure Crashes by Collision Type

The RwD crashes were categorized by the type of collision into several clusters such as: fixed object, head on, overturn/rollover, ran off the road-right, ran off the road-left, and side swipe. Collision with fixed object and ran off the road- right side respectively with 59% and 24% of RwD crashes constitute the core fraction of RwD crashes in Oahu. Table 4 shows the distribution of RwD crashes by type in each district. The percentages of fix object and ran off the road- right side collisions are relatively similar across the districts (making a total of approximately 80 % in both in each district); hence concentrating on countermeasures for these cases can be an effective strategy.

Table 4 Distribution of RwD Crash by Type in Oahu, Hawaii

RwD Crash Type	Fixed object	Head on	Overturn /Rollover	Ran off the road-right	Ran off the road-left	Side Swipe	Ground Total
District 1	57%	3%	1%	31%	2%	7%	**100%**
District 2	55%	5%	3%	21%	7%	10%	**100%**
District 3	65%	5%	3%	21%	1%	5%	**100%**
District 4	58%	5%	3%	21%	6%	8%	**100%**
District 5	64%	2%	2%	25%	2%	6%	**100%**
District 6	46%	1%	0%	40%	2%	10%	**100%**
District 7	54%	4%	1%	31%	2%	8%	**100%**
District 8	60%	4%	5%	21%	2%	9%	**100%**

3.2. Roadway Design

3.2.1. Trafficway Description

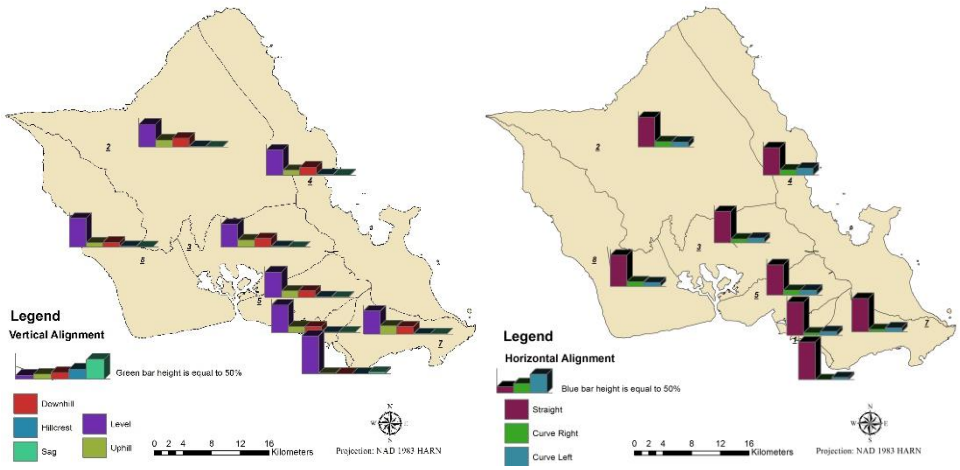
Table 5 shows that about 45% of RwD crashes occur in 2-way undivided roads but that the percentage of fatalities is only 40% on these facilities. Essentially, this type of road is apparently more dangerous than the other types listed in the table because vehicles can cross the centerline or median and crash into an approaching vehicle with higher impact speed. One of the reasons that can explain a higher rate of RwD fatalities in district 3 (Figure 4) is that most of crashes occurred in 2-way undivided roads, which are intrinsically more dangerous.

Table 5 Distribution of RwD Crash by traffic way description in Oahu, Hawaii

Traffic-way Description	Total Number of RwD Crashes	**Percentage**	**Fatalities**	**Percentage**
2-way, Undivided	2005	44.66%	31	39.74%
2-way, Divided, Median barrier	947	21.10%	22	28.21%
2-Way Undivided with Left Turn Lane	638	14.21%	12	15.38%
1-Way Trafficway	756	16.84%	8	10.26%
2-way, Divided, Unprotected Median	26	0.58%	3	3.85%
Other	117	2.61%	2	2.56%
Grand Total	4489	100.00%	78	100.00%

3.2.2. Horizontal Alignment & Vertical Alignment

The roadway geometry can affect the probability of RwD crashes occurrence. Interestingly, from the data in this study, it was found that 77.75% of vehicles in RwD crashes were circulating on straight roads (horizontal alignment), and 63.72% of them were located on level or zero grade roads (vertical alignment). Roads of district 4 are more winding and that is why on that district 31% of crashes occurred on curves. On the other hand, districts 2 and 3 have the highest rates of RwD crashes on hilly roads (at approximately 40%) which is commensurate to the topography of that region.

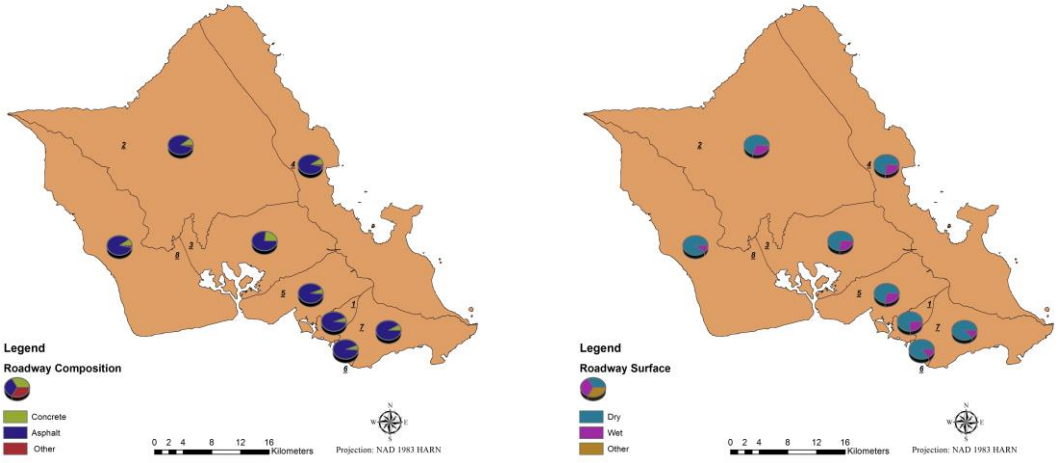


(a) *(b)*

Figure 5 Distribution of Geometric Design Categorizes in RwD Crash Occurrence a) Vertical Alignment b) Horizontal Alignment

3.2.3. Roadway Composition & Surface

Surface condition of roads is an important contributing factor to RwD crashes since the friction of the road surface/tire interface helps a driver to control the vehicle once it leaves the road. The results in Figure 6 illustrate that 87% of RwD crashes occurred in roads with asphalt pavements and 77% of all RwD crashes took place on dry surfaces. Meanwhile, 27% of RwD crashes fatalities occurred on wet road surfaces for which lower friction could be factor. Figure 6 shows the distribution of roadway composition and surface condition in RwD crashes in each districts.

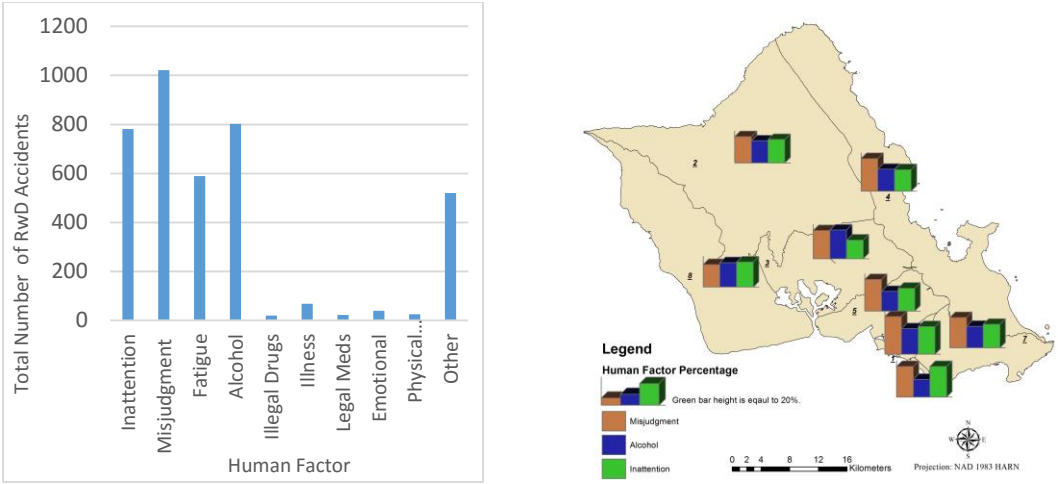


(a) *(b)*

Figure 6 Distribution of Road Surface Categorizes in RwD Crash Occurrence, a) Roadway Surface Composition, b) Roadway Surface Condition

3.3. Human Factors

The data analysis depicts that misjudgment, alcohol, and inattention are major human factors in RwD crashes. Figure 7(a) illustrates the role of miscellaneous human factors in frequency of RwD crashes. Figure 7(b) presents spatial distribution of three major human factors. The bar charts are derived by calculating the percentage of total number of RwD crashes caused by specific human factor to all human related RwD crashes.



(a) *(b)*

Figure 7 a) Total Number of RwD Crashes Categorized by Human Factors b) Distribution of Main Human Factors in RwD Crash Occurrence

3.4. Environmental Factors

The results of the analysis show that 82.5% of RwD accidents occurred in roads with light (daylight, continuous lighting or spot illumination), and 68.27% occurred in clear weather while 17.33% occurred under rainy conditions.

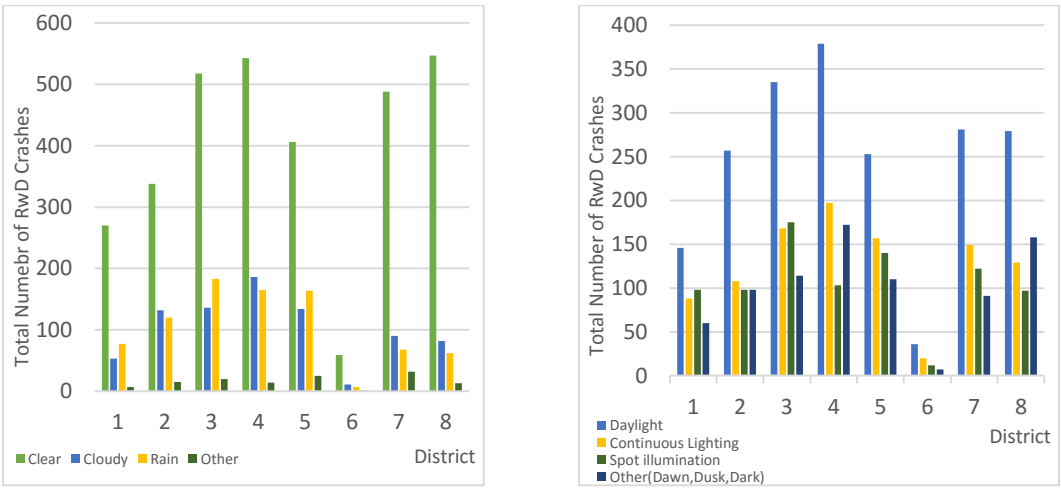


Figure 8 Distribution of Environmental categorizes in RwD Crash Occurrence a) Weather condition b) Lighting condition

3.5. Conditional Probabilistic Analysis of RwD Crashes

Unlike the previous sections which mostly presents distribution of RwD crashes by their existing contributing factors, this analysis present the role of each factor in probability of RwD crashes. Table (7-9) displays the results of Conditional probabilistic analysis by *Bayesian Statistical Approach*. For each contributing factor, the probability of the occurrence of RwD crashes associated with that factor is computed.

Table 6 Probability of Occurrence RwD crashes if classified crash class i (Roadway Design factor)

Trafficway Description	2-way, Undivided	2-way, Divided, Median barrier	2-Way Undivided with Left Turn Lane	1-Way Trafficway	2-way, Divided, Unprotected Median
$P(RwD\|C_i)$	25.64%	22.87%	24.35%	26.08%	9.42%

Vertical Alignment	Level	Hillcrest	Uphill	Downhill	Sag
$P(RwD\|C_i)$	16.77%	24.61%	28.16%	29.08%	33.78%

Roadway Surface	Dry	Wet	Mud	Debris	Oil	Water	Sand
$P(RwD\|C_i)$	17.90%	29.72%	35.71%	33.33%	70.00%	26.67%	33.33%

Roadway Composite	Concrete	Asphalt	Gravel	Dirt
$P(RwD\|C_i)$	23.93%	19.02%	44.44%	53.17%

Table 7 Probability of Occurrence RwD crashes if classified crash class i (Human Factor)

Human Factor	Inattention	Misjudgment	Fatigue	Alcohol	Illegal Drugs	Illness	Legal Meds.	Emotional	Physical Impaired
$P(RwD\|C_i)$	13.24%	19.19%	57.75%	42.21%	47.50%	47.52%	50.00%	38.24%	39.34%

Table 8 Probability of Occurrence RwD crashes if classified crash class i (Environmental Factor)

Lighting Condition	Daylight	Dawn	Dusk	Spot illumination	Continuous Lighting	Dark	Dark/No light	Dark/Unknown
$P(RwD\|C_i)$	17.02%	31.08%	25.50%	35.43%	32.22%	34.85%	50.98%	32.82%

Weather Condition	Clear	Cloudy	Rain	Hazy	Windy	Blowing Sand
$P(RwD\|C_i)$	21.76%	26.50%	36.26%	30.68%	27.10%	23.08%

4. Conclusion

Since a considerable share of roadway fatalities are RwD crashes, analyzing RwD crash data and exploring the contributing factors and potential countermeasures are an important step to reduce fatalities. Hence, RwD crash data was extracted form police crash reports of Oahu for 4 consecutive years (2008-2011), and the spatial distribution of contributing factors at the district level were identified. The crashes were analyzed in four aspects: characteristic of RwD crashes by locality and type of collision, roadway design factors, human and environmental factors. The results suggest that the probability of the occurrence of a RwD crash is higher in the following circumstances: Urban area, 2-way undivided roads, curvy roads, hilly roads, dirt and gravel surfaces, oily and wet road surface, fatigue and medical medicines consumption by driver, hazy weather, and dark/no light condition. Identification of these factors at the district level can better explain the occurrence of RwD crashes, and it can also ease the selection and location of countermeasure due to budget constraints.

Disclaimer

The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the facts presented herein. The contents do not necessarily reflect the official views or policies of the State of Hawaii, Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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