USING CIRCUITY TO INFORM BETTER TRANSPORTATION DECISIONS

ABSTRACT

Information is needed to inform transportation decisions between UAVs and ground modes of travel (e.g., delivery vans or robots). This research analytically demonstrates that circuity – the ratio of road distance over air distance – is correlated with the speed and cost of transportation. Knowing the circuity in an area is therefore important. Using empirical data from a set of 4477 routes from 90 cities, it develops a multilevel linear regression model to test the relationship of circuity with demographic and geographic variables, including route elevation change, average altitude, population, and proportion of land (i.e., total area minus waterbodies).

INTRODUCTION

Recent technological advances have elevated the viability of unmanned aerial vehicles (UAVs), commonly known as drones, for transportation, increasing potential uses for freight distribution and other logistics-related services such as parcel and health products deliveries. As the usefulness of UAVs has grown, so has the number of businesses incorporating this new technology into their operations attempting to become more competitive by either lowering costs or increasing service. In the United States, over 385,000 drones were being used for commercial purposes in 2019, and new registrations are currently growing at a rate of 10,000 per month [1]. In many developing countries UAVs are already used for last-mile deliveries. As regulations in the United States and other leading industrial nations increasingly allow UAVs for commercial activities, researchers and managers must determine the operational requirements and service potential of UAVs.

This research is important and timely because existing literature does not adequately inform the understanding of how air and ground routes are different. Therefore, this research aims to answer:

RQ1: How can the circuity ratio inform transportation mode decisions?

RQ2: How does circuity change as a function of spatial and demographic variables?

Circuity is defined as the ratio of network distance over Euclidean distance [2]. It has been frequently altered to fit research purposes. For example, some researchers have defined circuity as the ratio of a route with additional stops to a baseline route. Using this approach, Fricker [3] uses circuity to study the impacts of ridesharing, and Popkin [4] uses circuity to study dynamic routing with multiple orders. Boeing [5] uses circuity as a compound metric to compare walking and driving distances. Dill [6] used another variation of the ratio, termed it *pedestrian route directness,* and applied it to urbanism to study its impact on promoting cycling and walking in a city. Other terms used for circuity have been *route factor* and *detour index* [7]. Recently, in close comparison, Carlsson and Song [8] use the ratio of the speeds of trucks and UAVs deliveries (which are dependent on network and Euclidean routes, respectively) and find the square root of this ratio is proportional to the improvement in efficiency when a truck adds a UAV delivery component.

Based on a thorough literature review, we identified several factors that previous research has recognized as possible factors influencing the circuity ratio. Many of these factors have never been tested in an empirical setting. Therefore, this research develops and test the following hypotheses.

H1: As the elevation change between the start and end of a route increases, the circuity ratio increases.
H2: As the average altitude of a route increases, the circuity ratio increases.
H3: As population increases, the circuity ratio increases.
H4: As the proportion of land increases, the circuity ratio decreases.
H5: As the road density increases, the circuity ratio decreases.

RESULTS

Predictors	*Estimates*	*(std. Error)*	*Confidence Interval*	*p*
(Intercept)	0.39011 ***	(0.00802)	0.37439 – 0.40583	**<0.001**
Elevation change (Δh)	0.01327 ***	(0.00385)	0.00573 – 0.02082	**0.001**
Altitude ($\bar{h}$)	0.06935 ***	(0.00885)	0.05201 – 0.08669	**<0.001**
Population (p)	0.01844	(0.01627)	-0.01345 – 0.05033	0.257
Proportion land (l)	-0.03259 ***	(0.00889)	-0.05002 – -0.01516	**<0.001**
Road density (s)	-0.02514	(0.01761)	-0.05966 – 0.00937	0.153
Random Effects				
Within-city variance σ_{ε}^2	0.035			
Between-city variance σ_{u0}^2	0.005			
Intraclass Correlation Coef. ICC	0.127			
N_{CITY}	90			
Observations	4477			
Marginal R^2 / Conditional R^2	0.145 / 0.255			
AIC	-2152.1			

* *p<0.05* ** *p<0.01* *** *p<0.001*

As shown in the table above, the variable elevation change, altitude, and proportion of land significantly impact the circuity ratio, whereas population and road density do not.

CONCLUSION

This research analytically demonstrates that circuity – the ratio of road distance over air distance – is correlated with the speed and cost of transportation. It then further investigates the characteristics of circuity using empirical data. The findings of this research facilitate logisticians' knowledge for making strategic.

REFERENCES

[1] FAA 2020. "FAA Aerospace Forecast: Fiscal Years 2020-2040", available at https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2020-40_faa_aerospace_forecast.pdf. (accessed October 26, 2021).

[2] Ballou, R. H., Rahardja, H. and Sakai, N. 2002. "Selected country circuity factors for road travel distance estimation". *Transportation Research Part A: Policy and Practice,*36(9), pp. 843-848.

[3] Fricker, J. 1986. "Circuity factor values in ridesharing: a detailed update". *Transportation Research Record*, Vol 1082, pp. 34-40.

[4] Popken, D. A. 2006. "Controlling order circuity in pickup and delivery problems". *Transportation Research Part E: Logistics and Transportation Review,*42(5), pp. 431-443.

[5] Boeing, G. 2018. "The Relative Circuity of Walkable and Drivable Urban Street Networks". paper presented at Transportation Research Board 97th Annual Meeting, January 7-11, Washington, DC.

[6] Dill, J. 2004. "Measuring network connectivity for bicycling and walking", paper presented at the 83rd Annual Meeting of the Transportation Research Board, January 11-15, Washington, DC.

[7] Barthélemy, M. 2011. "Spatial networks". *Physics Reports,* 499(1–3), pp. 1-101.

[8] Carlsson, J. G., and Song, S. 2018. "Coordinated logistics with a truck and a drone". *Management Science*, 64(9), 4052-4069.