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Application of Artificial Neural Network for Modelling and Predicting Roundabout Capacity

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objective

- The operational performance analysis of roundabouts in **Greece** is based on existing practices and guidelines from the **U.S.A.**
- They are adapted on the local driving behavior of American drivers.
- Existing capacity models may **not be applicable** today.
- the selection of the analysis method and of the input data can give variation in capacity estimates and affect the current roundabout design practices.

1. **geometric** roundabout features & driving **behavior** parameters

2. **neural network** modelling of entry lane **capacity** of roundabouts

3. **assessment** of **existing** roundabout capacity models

structure

Introduction

Methodology

Analysis

Results & Conclusions

roundabout capacity and ANN

The ability to predict **accurately** the roundabout lane capacity can **improve** the **performance** of a roundabout either by optimizing proposed design solutions or by enhancing proper interventions on existing roundabout layouts.

The current context is characterized by **gradual changes in vehicles technology** and **variations in drivers' behavior** as they get more familiar with roundabouts.

The revolution of the modern automotive industry entails that the existing roadway design standards and guidelines need to be examined to a wider range of scenarios.

A **flexible** approach capable of modelling potential **complex relationships** of future road conditions is required for an efficient estimation of roundabout entry lane capacity.

Artificial neural networks (ANN) are recommended for complex relationships.

methodology

Site selection

- geometric elements
- traffic volumes
- location characteristics

- single lane and multilane roundabouts of various geometric elements
- queued conditions
- psychotechnical parameters of vehicle drivers

- **50** entry lanes
- **15** roundabouts
- **6** municipalities

equipment

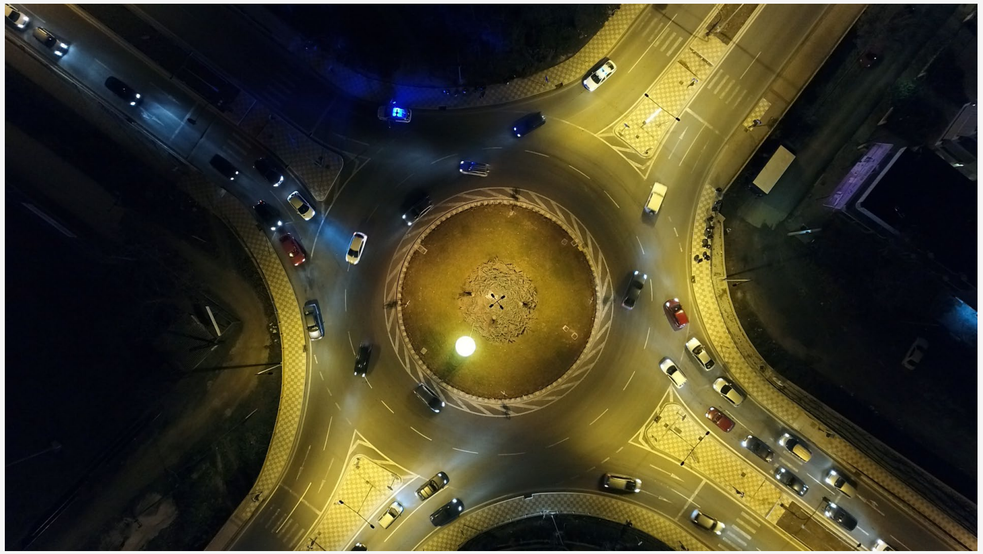
Survey material and equipment

quadcopter UAV

C4K / 60fps / 5472x3078

RTK GNSS receiver

8mm+1ppm / 15mm+1ppm



- Naturalistic driving behavior
- Less experience and training
- Wide filed of view
- Saving-time, low-cost & non-infrastructure-based technique

−

- Weather conditions (rain)
- Technical issues (low battery duration)
- Regulatory issues (no-fly zones)

Video camera attached to a tripod

3840x2160/ 30fps

methodology

Examined roundabout sites

- **282** one-minute observations
- **Peak time** periods
- **PCUs** per hour

Type of Extracted Parameters	Type of Roundabout
TF, GP, PP	Multi-lane
TF, GP, PP	Multi-lane
GP, PP	Multi-lane
TF, GP, PP	Multi-lane
GP, PP	Multi-lane
TF, GP, PP	Single-lane
TF, GP, PP	Single-lane
TF, GP, PP	Multi-lane
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TF, GP, PP	Single-lane
GP, PP	Multi-lane
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TF, GP, PP	Multi-lane
GP, PP	Multi-lane

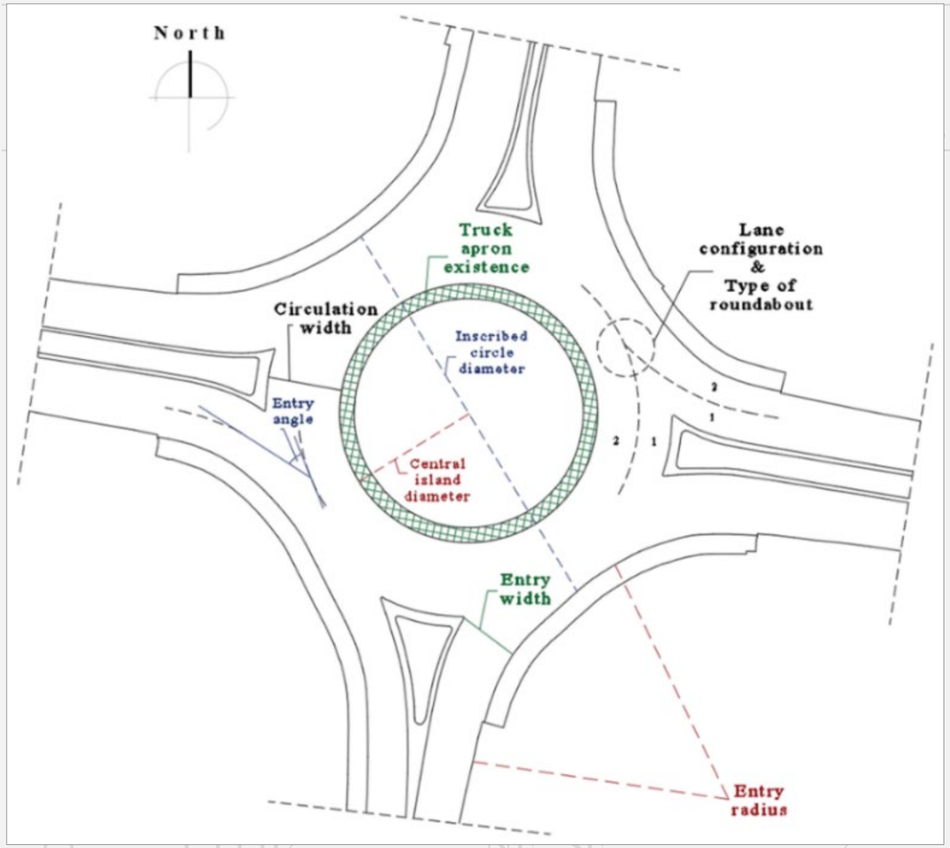
10
5

TF: traffic flows (2)

- *entry flow*
- *circulating flow*

methodology

Examined roundabout sites



Type of Extracted Parameters	Type of Roundabout	
TF, GP, PP	Multi-lane	
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TF, GP, PP	Multi-lane	
GP, PP	Multi-lane	
TF, GP, PP	Single-lane	
TF, GP, PP	Single-lane	
TF, GP, PP	Multi-lane	**10**
GP, PP	Single-lane	**5**
TF, GP, PP	Single-lane	
TF, GP, PP	Single-lane	
GP, PP	Multi-lane	
TF, GP, PP	Multi-lane	
TF, GP, PP	Multi-lane	
GP, PP	Multi-lane	

GP: <u>geometric parameters</u> (9)

- *entry width*
- *entry radius*
- *entry angle*
- *circulatory roadway width*
- *inscribed circle diameter*
- *truck apron existence*
- *central island diameter*
- type of roundabout
- lane configuration

methodology

Examined roundabout sites

Lane Configuration	t_f	sample (n)	t_c	sample (n)
1 x 1	2.953	1,447	4.139	338
1 x 2	2.625	979	4.390	321
2L x 2	2.674	326	4.702	130
2R x 2	2.513	723	4.613	156
Single lane Sites	2.953	1,447	4.139	338
Multilane Sites	2.593	2,028	4,514	607

pe of racted meters	Type of Roundabout
GP, PP	Multi-lane
GP, PP	Multi-lane
, PP	Multi-lane
GP, PP	Multi-lane
, PP	Multi-lane
GP, PP	Single-lane
GP, PP	Single-lane
GP, PP	Multi-lane
, PP	Single-lane
GP, PP	Single-lane
GP, PP	Single-lane
, PP	Multi-lane
GP, PP	Multi-lane
GP, PP	Multi-lane
, PP	Multi-lane

10

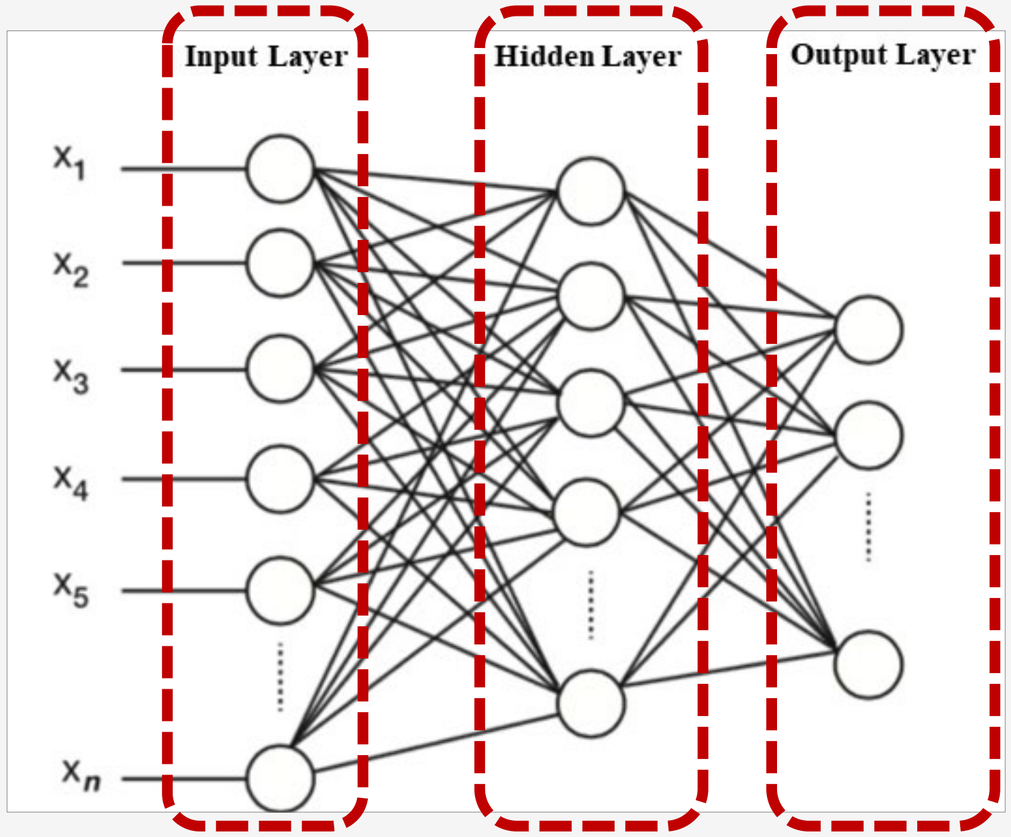
5

- tc: *the minimum headway an entering driver would find acceptable* - Maximum Likelihood Technique
- tf: *the headway maintained by two consecutive entering vehicles using the same gap in the conflicting stream* - move-up time method

PP: psychotechnical parameters (2)

- *critical headway (tc)*
- *follow-up headway (tf)*

ANN Modelling of Roundabout Capacity



- mathematical models
- large datasets
- complex relationships
- category of empirical capacity models
- limited number of studies

analysis

Explanatory variables

based on
(a) **previous models** and
(b) causal mechanisms suggested by existing literature

A. Quantitative Variables

Variable	Min	Max	Mean	Std. Dv.
Entry flow	60	1,560	732.3	274,99
Circulating flow	60	1,320	515.2	298.24
Follow-up headway (t_f)	2.2	3.4	2.8	0.30
Critical headway (t_c)	3.7	5.3	4.2	0.38
Entry width	2.8	6.2	4.8	1.04
Entry radius	4.4	53.5	17.09	11.22
Entry angle	6.0	72.0	32.72	18.60
Circulatory roadway width	6.0	10.0	7.47	1.46
Inscribed circle diameter	24.0	70.0	40.69	15.36
Central island diameter	12.0	55.0	25.75	14.22

Correlation analysis

normality of data distribution → Kolmogorov Smirnov (K-S) test

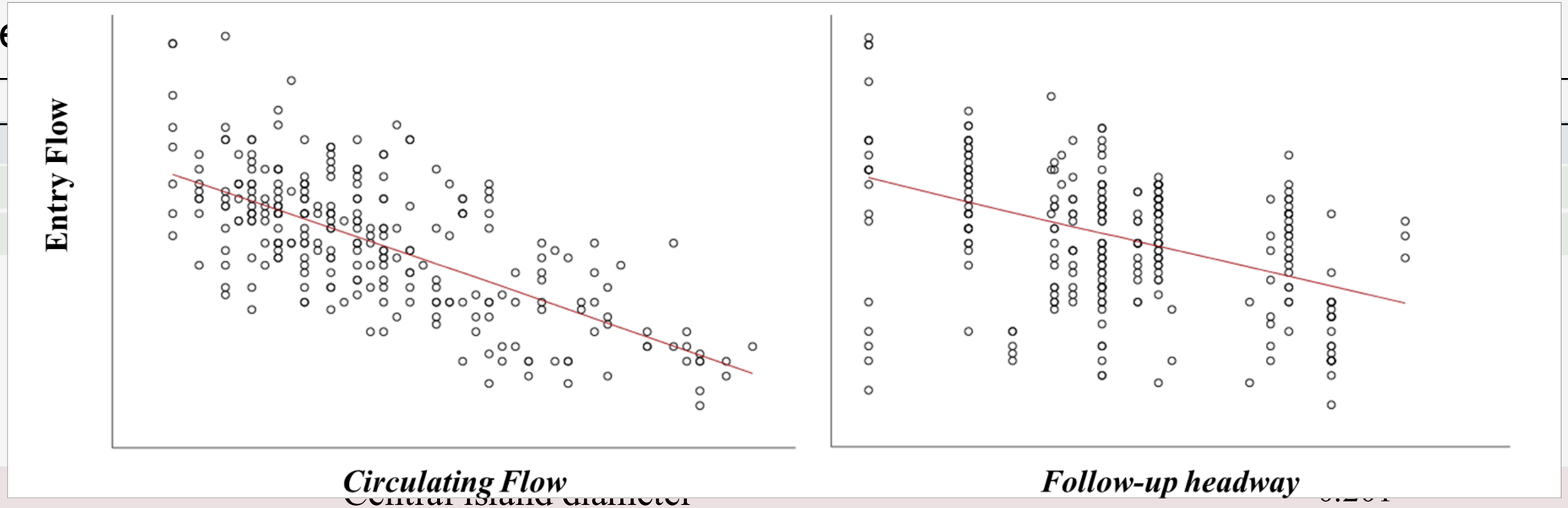
$p < 0.05$

Spearman's Rho Correlation analysis

Variables	Correlation Coefficient
Circulating flow	-0.622**
Follow-up headway (t_f)	-0.384**
Critical headway (t_c)	-0.232**
Entry width	0.042
Entry radius	-0.012
Entry angle	-0.068
Circulatory roadway width	-0.049
Inscribed circle diameter	0.138*
Central island diameter	0.201**

analysis

Spe



Central island diameter

Explanatory variables

B. Qualitative Variables

1. Type of the roundabout: 1= Single lane, 2 = Multilane

2. Truck apron: 1= existence of truck apron, 2 = lack of truck apron

3. Lane configuration: number of entry and circulating lanes

Lane Configuration	Type of Roundabout	Description	Code
1 x 1	Single lane	1 entering lane and 1 circulating lane	1
1 x 2	Multilane	1 entering lane and 2 circulating lanes	2
2L x 2	Multilane	left entering lane and 2 circulating lanes	3
2R x 2	Multilane	right entering lane and 2 circulating lanes	4

analysis

Artificial Neural Networks

Dataset (267 cases)

- 70 % training
- 20% testing
- 10% validation

- method
- architecture

A simple feed-forward **multilayer perceptron Neural Network** (**MLP**) with hyperbolic tangent activation function of hidden layer and identity activation function of output layers was sufficient to account for most of the model fit

- set of explanatory variables

ANN model including **all** the explanatory variables resulted in better predictions

Architecture Information of the optimum ANN model

	Input Layer	Hidden Layer		Outout Layer	
Factors	Type of roundabout Lane configuration Truck apron existence	Number of hidden layers	1	Dependent variables	Entry flow
Covariates	Circulating flow Follow-up headway (t_f) Critical headway (t_c) Entry width Entry radius Entry angle Circ. roadway width Inscribed circle diameter Central island diameter	Num. of units in hidden layer 1[a]	8	Number of units	1
		Activation function	Hyperbolic tangent	Resc. method for scale dependents	Standardized
				Activ. function	Identity
				Error function	Sum of squares

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Model Summary

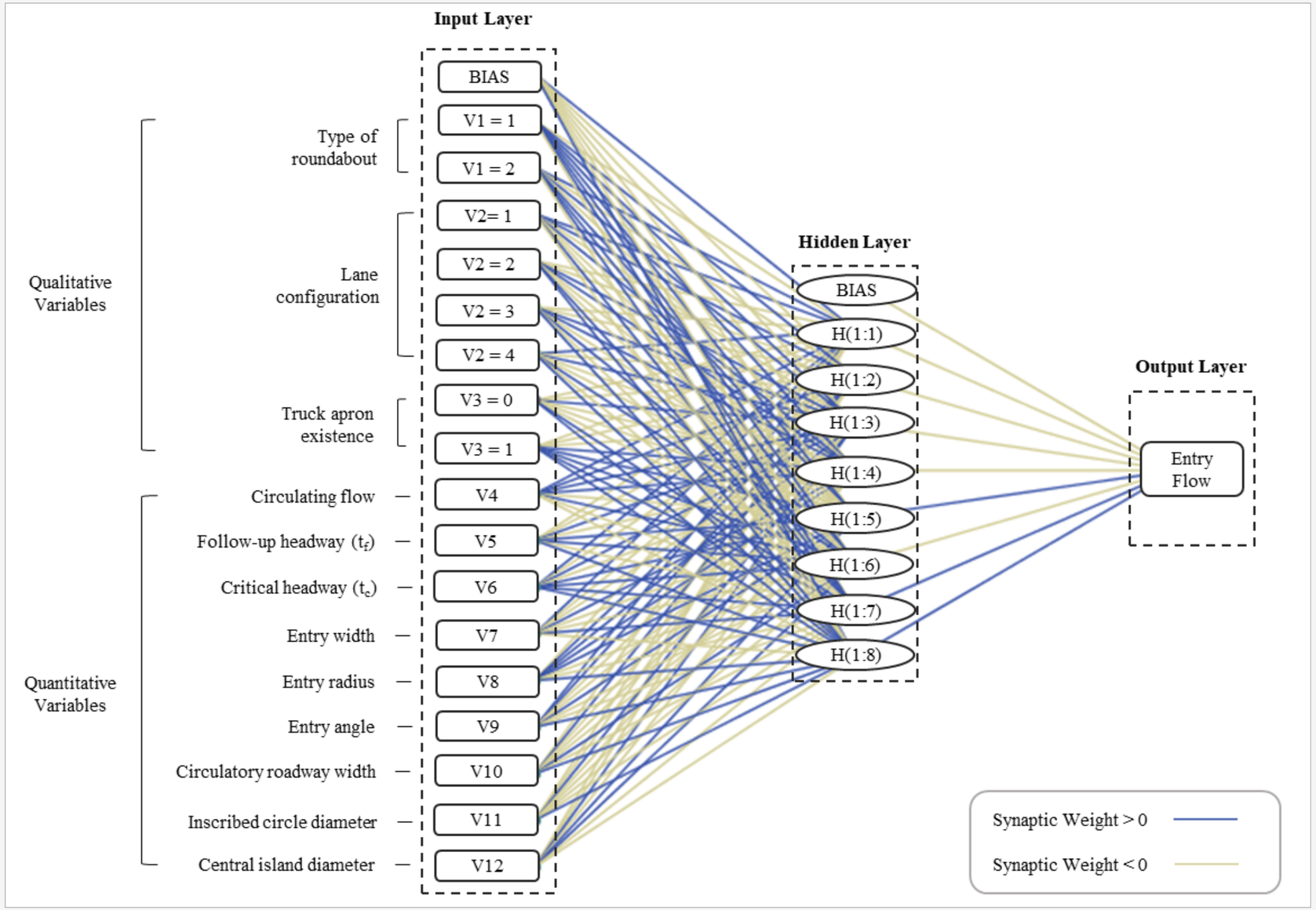
Training		Testing		Holdout	
Sum of squarer error	21.174	Sum of squarer error	4.967	Relative error	0.201
Relative error	0.219	Relative error	0.228		

fairly constant

↓

not overtrained

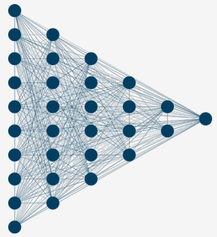
results



- R^2 = 0.78
- RMSE = 129.44

assessment of existing roundabout capacity models

ANN



VS

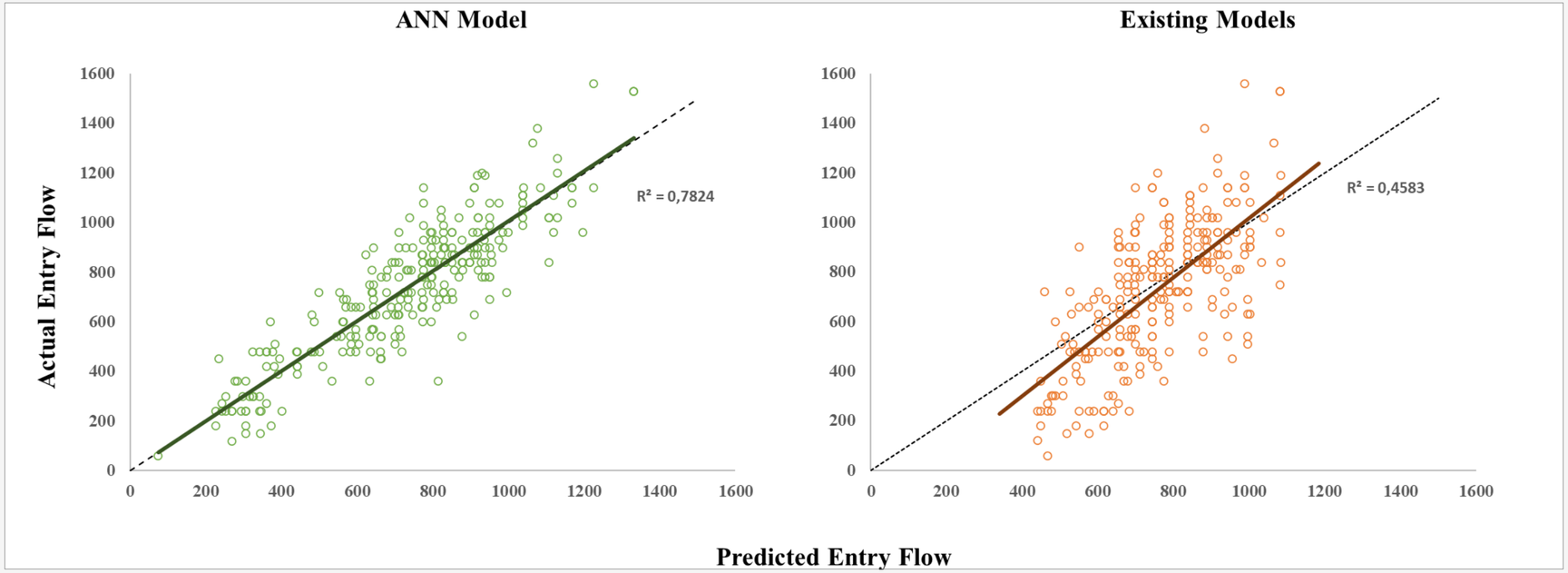
HCM 2010

$c = 1130xe^{(-0.001)v}$

$c = 1130xe^{(-0.0007)v}$

$c = 1130xe^{(-0.00075)v}$

Model	Description	Mean R^2	Mean RMSE
Greek Guidelines/ HCM 2010	Exponential regression	0.46	206.23
Artificial Neural Network	MLP	0.78	129.44



conclusions

An **empirical analysis** is described in this presentation, using **traffic flow data** under **oversaturated periods** from **50 entry lanes** of **15 roundabouts** in Greece.

The proposed methodology addresses the use of **machine learning techniques** for a **proactive operational plan for roundabouts.**

According to the **correlation analysis**, it can be concluded that the **traffic flow** parameters, the **geometric characteristics** and the **psychotechnical parameters** of vehicles drivers affect the entry lane capacity of roundabouts.

More specifically, the circulating traffic flow and the follow-up headway of vehicles at the entrance of the roundabout are strongly related to the entry traffic flow.

The developed **ANN** model predicts much better the actual roundabout entry lane capacity against the existing models as used by the Greek guidelines.

limitations

Although a significant number of the explanatory variables affecting capacity was considered for the development of the models, there are factors that have not been investigated because of **limited resources** (e.g., impact of the exit flow).

Another limitation of this study is that ANN models were **validated** based on a **limited** dataset.

future research

Further research is required before the general application of the proposed model in practice.

An **extension** and **validation** of the empirical model is required.

- More capacity flow measurements through a geographically wide database will extend the capability of the model.
- Moreover, the applicability of the proposed model should be examined in more case studies.
- The transferability of the model in other countries can be examined as well.

Thank you!