In-class Exercise 4: Calibrating Spatial Interaction Models with R

2023-01-24

## Overview

This in-class exercise is a continuation of Hands-on Exercise 3, In-class Exercise 3 and In-class Exercise 4: Preparing Spatial Interaction Modelling Variables. We will continue our journey of calibrating Spatial Interaction Models by using propulsiveness and attractiveness variables prepared in earlier in-class exercise.

## Getting Started

For the purpose of this exercise, five r packages will be used. They are:

* **sf** for importing, integrating, processing and transforming geospatial data.
* **tidyverse** for importing, integrating, wrangling and visualising data.
* **tmap** for plotting cartographicquality thematic maps.
* [performance](https://easystats.github.io/performance/) for computing model comparison matrices such as rmse.
* [ggpubr](https://rpkgs.datanovia.com/ggpubr/) for creating publication quality statistical graphics.

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| Do it yourself |
| Using the steps you learned in previous exercises, load the above packages onto R environment. |

pacman::p\_load(tmap, sf, performance, knitr,  
 ggpubr, tidyverse)

## The Data

This exercise is a continuation of Hands-on Exercise 3 and In-class Exercise 4: Preparing Spatial Interaction Modelling Variables. The following data will be used:

* *flow\_data\_tidy.rds*, weekday morning peak passenger flows at planning subzone level.
* *mpsz.rds*, URA Master Plan 2019 Planning Subzone boundary in simple feature tibble data frame format.

flow\_data <- read\_rds("data/rds/flow\_data\_tidy.rds")

glimpse(flow\_data)

Rows: 14,734  
Columns: 13  
$ ORIGIN\_SZ <chr> "AMSZ01", "AMSZ01", "AMSZ01", "AMSZ01", "AMSZ01", "AMS…  
$ DESTIN\_SZ <chr> "AMSZ01", "AMSZ02", "AMSZ03", "AMSZ04", "AMSZ05", "AMS…  
$ TRIPS <dbl> 1998, 8289, 8971, 2252, 6136, 2148, 1620, 1925, 1773, …  
$ DIST <dbl> 50.0000, 810.4491, 1360.9294, 840.4432, 1076.7916, 805…  
$ ORIGIN\_AGE7\_12 <dbl> 310, 310, 310, 310, 310, 310, 310, 310, 310, 310, 310,…  
$ ORIGIN\_AGE13\_24 <dbl> 710, 710, 710, 710, 710, 710, 710, 710, 710, 710, 710,…  
$ ORIGIN\_AGE25\_64 <dbl> 2780, 2780, 2780, 2780, 2780, 2780, 2780, 2780, 2780, …  
$ DESTIN\_AGE7\_12 <dbl> 310.00, 1140.00, 1010.00, 980.00, 810.00, 1050.00, 420…  
$ DESTIN\_AGE13\_24 <dbl> 710.00, 2770.00, 2650.00, 2000.00, 1920.00, 2390.00, 1…  
$ DESTIN\_AGE25\_64 <dbl> 2780.00, 15700.00, 14240.00, 11320.00, 9650.00, 12460.…  
$ SCHOOL\_COUNT <dbl> 0.99, 2.00, 2.00, 1.00, 3.00, 2.00, 0.99, 0.99, 3.00, …  
$ BUSINESS\_COUNT <dbl> 1.00, 0.99, 6.00, 0.99, 0.99, 0.99, 1.00, 117.00, 0.99…  
$ geometry <LINESTRING [m]> LINESTRING (29501.77 39419...., LINESTRING …

Notice that this sf tibble data.frame includes two additional fields namely: *SCHOOL\_COUNT* and *BUSINESS\_COUNT*. Both of them will be used as attractiveness variables when calibrating origin constrained SIM.

The code chunk below is used to display the first five columns and rows of *flow\_data*.

kable(head(flow\_data[, 1:5], n = 5))

| ORIGIN\_SZ | DESTIN\_SZ | TRIPS | DIST | ORIGIN\_AGE7\_12 | geometry |
| --- | --- | --- | --- | --- | --- |
| AMSZ01 | AMSZ01 | 1998 | 50.0000 | 310 | LINESTRING (29501.77 39419…. |
| AMSZ01 | AMSZ02 | 8289 | 810.4491 | 310 | LINESTRING (29501.77 39419…. |
| AMSZ01 | AMSZ03 | 8971 | 1360.9294 | 310 | LINESTRING (29501.77 39419…. |
| AMSZ01 | AMSZ04 | 2252 | 840.4432 | 310 | LINESTRING (29501.77 39419…. |
| AMSZ01 | AMSZ05 | 6136 | 1076.7916 | 310 | LINESTRING (29501.77 39419…. |

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| Important |
| Notice that this data.frame include intra-zonal flow. |

### Preparing inter-zonal flow data

In general, we will calibrate separate Spatial Interaction Models for inter- and intra-zonal flows. In this hands-on exercise, we will focus our attention on inter-zonal flow. Hence, we need to exclude the intra-zonal flow from *flow\_data*.

First, two new columns called *FlowNoIntra* and *offset* will be created by using the code chunk below.

flow\_data$FlowNoIntra <- ifelse(  
 flow\_data$ORIGIN\_SZ == flow\_data$DESTIN\_SZ,   
 0, flow\_data$TRIPS)  
flow\_data$offset <- ifelse(  
 flow\_data$ORIGIN\_SZ == flow\_data$DESTIN\_SZ,   
 0.000001, 1)

According to the syntax used to derive values in *FlowNoIntra* field, all intra-zonal flow will be given a value of 0 or else the original flow values will be inserted.

Next, inter-zonal flow will be selected from flow\_data and save into a new output data.frame called *inter\_zonal\_flow* by using the code chunk below.

inter\_zonal\_flow <- flow\_data %>%  
 filter(FlowNoIntra > 0)

You are ready to calibrate the Spatial Interaction Models now.

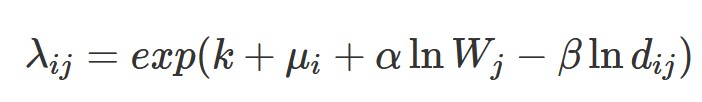
## Calibrating Spatial Interaction Models

In this section, we will focus on calibrating an origin constrained SIM and a doubly constrained by using *flow\_data* prepared. They complement what you have learned in Hands-on Exercise 3.

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| Note |
| Students are encouraged to revise the lesson slides as well as Sub-section 2.2 of Kingsley E. Haynes and A. Stewart Fotheringham (2020) [**Gravity and Spatial Interaction Models**](https://researchrepository.wvu.edu/rri-web-book/16/). |

### Origin- (Production-) constrained Model

Figure below shows the general formula of the origin-constrained model.



Code chunk below shows the calibration of the model by using [glm()](https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/glm) of R and *flow\_data*.

orcSIM\_Poisson <- glm(formula = TRIPS ~   
 ORIGIN\_SZ +  
 log(SCHOOL\_COUNT) +  
 log(BUSINESS\_COUNT) +  
 log(DIST) - 1,  
 family = poisson(link = "log"),  
 data = inter\_zonal\_flow,  
 na.action = na.exclude)  
summary(orcSIM\_Poisson)

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| Things to learning from the conde chunk |
| * For origin-constrained model, only explanatory variables representing the attractiveness at the destinations will be used. * All the explanatory variables including distance will be log transformed. * *ORIGIN\_SZ* is used to model 𝜇𝑖 . It must be in categorical data type. * It is important to note that -1 is added in the equation after the distance variable. The -1 serves the purpose of removing the intercept that by default, glm will insert into the model. |

Call:  
glm(formula = TRIPS ~ ORIGIN\_SZ + log(SCHOOL\_COUNT) + log(BUSINESS\_COUNT) +   
 log(DIST) - 1, family = poisson(link = "log"), data = inter\_zonal\_flow,   
 na.action = na.exclude)  
  
Coefficients:  
 Estimate Std. Error z value Pr(>|z|)   
ORIGIN\_SZAMSZ01 19.8739840 0.0047627 4172.84 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ02 20.5902203 0.0042786 4812.33 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ03 20.2327026 0.0045531 4443.70 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ04 19.7744438 0.0049837 3967.79 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ05 19.6574529 0.0056396 3485.61 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ06 19.9659115 0.0048946 4079.16 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ07 18.6746164 0.0096316 1938.90 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ08 19.2701601 0.0090776 2122.82 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ09 19.9889467 0.0052858 3781.64 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ10 20.3422035 0.0045778 4443.62 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ11 18.3944113 0.0129212 1423.58 <2e-16 \*\*\*  
ORIGIN\_SZAMSZ12 18.3484209 0.0109652 1673.33 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ01 20.9668587 0.0043388 4832.36 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ02 20.4059518 0.0050601 4032.75 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ03 20.6725514 0.0045276 4565.93 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ04 21.6703853 0.0038930 5566.44 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ05 20.7497445 0.0046085 4502.46 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ06 20.9119361 0.0046432 4503.77 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ07 18.9749815 0.0097896 1938.28 <2e-16 \*\*\*  
ORIGIN\_SZBDSZ08 19.1933901 0.0091312 2101.95 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ01 19.5422606 0.0064732 3018.96 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ02 20.1748913 0.0050076 4028.89 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ03 20.3984624 0.0047226 4319.35 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ04 19.6182212 0.0059652 3288.76 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ05 19.6033818 0.0063181 3102.74 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ06 19.7145224 0.0056372 3497.20 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ07 20.4237448 0.0041912 4873.03 <2e-16 \*\*\*  
ORIGIN\_SZBKSZ08 19.7992538 0.0050405 3928.02 <2e-16 \*\*\*  
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ORIGIN\_SZBLSZ01 17.7977276 0.0149058 1194.01 <2e-16 \*\*\*  
ORIGIN\_SZBLSZ02 17.4287491 0.0192364 906.03 <2e-16 \*\*\*  
ORIGIN\_SZBLSZ03 16.5884288 0.0459848 360.74 <2e-16 \*\*\*  
ORIGIN\_SZBLSZ04 17.7851626 0.0232823 763.89 <2e-16 \*\*\*  
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ORIGIN\_SZBMSZ13 19.5654046 0.0057517 3401.70 <2e-16 \*\*\*  
ORIGIN\_SZBMSZ14 19.0685619 0.0063346 3010.24 <2e-16 \*\*\*  
ORIGIN\_SZBMSZ15 19.4403124 0.0058147 3343.30 <2e-16 \*\*\*  
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ORIGIN\_SZBMSZ17 18.3430175 0.0157692 1163.22 <2e-16 \*\*\*  
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ORIGIN\_SZBPSZ02 19.8116707 0.0061485 3222.19 <2e-16 \*\*\*  
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ORIGIN\_SZBPSZ04 20.4613200 0.0048398 4227.72 <2e-16 \*\*\*  
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ORIGIN\_SZBSSZ03 19.5428803 0.0052713 3707.41 <2e-16 \*\*\*  
ORIGIN\_SZBTSZ01 20.0198045 0.0058541 3419.77 <2e-16 \*\*\*  
ORIGIN\_SZBTSZ02 19.3618525 0.0081472 2376.51 <2e-16 \*\*\*  
ORIGIN\_SZBTSZ03 19.5883853 0.0068935 2841.59 <2e-16 \*\*\*  
ORIGIN\_SZBTSZ04 18.7720238 0.0103909 1806.58 <2e-16 \*\*\*  
ORIGIN\_SZBTSZ05 18.8069026 0.0120628 1559.08 <2e-16 \*\*\*  
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ORIGIN\_SZBTSZ08 18.6989374 0.0109610 1705.94 <2e-16 \*\*\*  
ORIGIN\_SZCBSZ01 18.2189868 0.0548317 332.27 <2e-16 \*\*\*  
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ORIGIN\_SZCHSZ01 19.5955119 0.0121035 1619.00 <2e-16 \*\*\*  
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ORIGIN\_SZCHSZ03 21.2164518 0.0063552 3338.43 <2e-16 \*\*\*  
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ORIGIN\_SZCLSZ03 19.0225512 0.0080145 2373.51 <2e-16 \*\*\*  
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ORIGIN\_SZYSSZ03 21.6614437 0.0040011 5413.81 <2e-16 \*\*\*  
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ORIGIN\_SZYSSZ09 20.9366181 0.0040347 5189.15 <2e-16 \*\*\*  
log(SCHOOL\_COUNT) 0.4755516 0.0004701 1011.55 <2e-16 \*\*\*  
log(BUSINESS\_COUNT) 0.1796905 0.0001856 968.12 <2e-16 \*\*\*  
log(DIST) -1.6929522 0.0004093 -4136.01 <2e-16 \*\*\*  
---  
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
  
(Dispersion parameter for poisson family taken to be 1)  
  
 Null deviance: 189463537 on 14471 degrees of freedom  
Residual deviance: 15526121 on 14189 degrees of freedom  
AIC: 15615824  
  
Number of Fisher Scoring iterations: 6

|  |
| --- |
| What can we learn from the report above? |
| * the ⍺1 and ⍺2 of *SCHOOL\_COUNT* and *BUSINESS\_COUNT* are 0.4755516 and 0.1796905 respectively. * 𝛽, the distance decay parameter is -1.6929522 * there are a series of parameters which are the vector of 𝜇𝑖 values associated with the origin constraints. |

### Goodness of fit

In statistical modelling, the next question we would like to answer is how well the proportion of variance in the dependent variable (i.e. TRIPS) that can be explained by the explanatory variables.

In order to provide answer to this question, R-squared statistics will be used. However, R-squared is not an output of glm(). Hence we will write a function called CalcRSquared by using the code chunk below.

CalcRSquared <- function(observed, estimated){  
 r <- cor(observed, estimated)  
 R2 <- r^2  
 R2  
}

NOw, we can examine how the constraints hold for destinations this time.

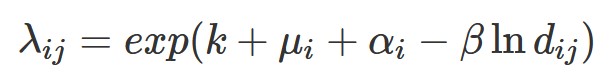
CalcRSquared(orcSIM\_Poisson$data$TRIPS, orcSIM\_Poisson$fitted.values)

[1] 0.4362208

With reference to the R-Squared above, we can conclude that the model accounts for about 44% of the variation of flows in the systems. Not bad, but not brilliant either.

### Doubly constrained model

In this section, we will fit a doubly constrained SIM by using the general formula shown below:



and the code chunk used is shown below.

dbcSIM\_Poisson <- glm(formula = TRIPS ~   
 ORIGIN\_SZ +   
 DESTIN\_SZ +  
 log(DIST),  
 family = poisson(link = "log"),  
 data = inter\_zonal\_flow,  
 na.action = na.exclude)  
summary(dbcSIM\_Poisson)

|  |
| --- |
| Important |
| It is important to note that there is a slight change of the code chunk. I have removed the -1 which means that an intercept will appear in the model again. This is not because I want an intercept as it makes the origin and destination coefficients harder to interpret, rather the -1 cheat for removing the intercept only works with one factor level but in double-constrained model we have two factor levels, namely: origins and destinations. |

Call:  
glm(formula = TRIPS ~ ORIGIN\_SZ + DESTIN\_SZ + log(DIST), family = poisson(link = "log"),   
 data = inter\_zonal\_flow, na.action = na.exclude)  
  
Coefficients:  
 Estimate Std. Error z value Pr(>|z|)   
(Intercept) 21.8312374 0.0059160 3690.190 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ02 0.5263502 0.0048031 109.585 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ03 0.3139982 0.0049254 63.751 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ04 -0.2146257 0.0053639 -40.013 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ05 -0.1890446 0.0060386 -31.306 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ06 0.1539201 0.0054401 28.294 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ07 -0.9826565 0.0098676 -99.584 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ08 -0.4488417 0.0093070 -48.226 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ09 0.0713474 0.0057402 12.429 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ10 0.4313742 0.0050370 85.641 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ11 -1.4712226 0.0131178 -112.154 < 2e-16 \*\*\*  
ORIGIN\_SZAMSZ12 -1.7250733 0.0111603 -154.573 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ01 0.8810576 0.0048168 182.914 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ02 0.1100240 0.0055529 19.814 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ03 0.3606166 0.0050672 71.167 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ04 1.4624347 0.0044212 330.781 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ05 0.6207557 0.0050843 122.092 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ06 0.6712973 0.0051953 129.214 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ07 -1.2338669 0.0100775 -122.437 < 2e-16 \*\*\*  
ORIGIN\_SZBDSZ08 -1.0444562 0.0094555 -110.460 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ01 -0.2838426 0.0071354 -39.780 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ02 0.5550522 0.0059014 94.054 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ03 0.7396640 0.0056796 130.231 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ04 -0.2242451 0.0067482 -33.230 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ05 -0.2371614 0.0069386 -34.180 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ06 -0.1413812 0.0065035 -21.739 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ07 0.7089989 0.0051843 136.758 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ08 -0.0907065 0.0059157 -15.333 < 2e-16 \*\*\*  
ORIGIN\_SZBKSZ09 -0.1775146 0.0063302 -28.042 < 2e-16 \*\*\*  
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ORIGIN\_SZBLSZ02 -2.8078475 0.0197839 -141.926 < 2e-16 \*\*\*  
ORIGIN\_SZBLSZ03 -3.3122763 0.0466091 -71.065 < 2e-16 \*\*\*  
ORIGIN\_SZBLSZ04 -2.6770542 0.0241793 -110.717 < 2e-16 \*\*\*  
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ORIGIN\_SZBMSZ12 -1.5323954 0.0099932 -153.344 < 2e-16 \*\*\*  
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ORIGIN\_SZBPSZ03 0.3358227 0.0070460 47.662 < 2e-16 \*\*\*  
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ORIGIN\_SZBPSZ07 -0.5467931 0.0091676 -59.644 < 2e-16 \*\*\*  
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DESTIN\_SZJESZ01 -0.3704281 0.0056684 -65.350 < 2e-16 \*\*\*  
DESTIN\_SZJESZ02 -0.7369159 0.0058686 -125.570 < 2e-16 \*\*\*  
DESTIN\_SZJESZ03 -0.8985484 0.0063627 -141.222 < 2e-16 \*\*\*  
DESTIN\_SZJESZ04 -1.0511995 0.0073996 -142.061 < 2e-16 \*\*\*  
DESTIN\_SZJESZ05 -1.5324974 0.0102612 -149.349 < 2e-16 \*\*\*  
DESTIN\_SZJESZ06 0.3105267 0.0048241 64.370 < 2e-16 \*\*\*  
DESTIN\_SZJESZ07 -1.3234483 0.0085497 -154.795 < 2e-16 \*\*\*  
DESTIN\_SZJESZ08 -0.6559742 0.0083174 -78.867 < 2e-16 \*\*\*  
DESTIN\_SZJESZ09 0.2663752 0.0063370 42.035 < 2e-16 \*\*\*  
DESTIN\_SZJESZ10 0.8529026 0.0076067 112.126 < 2e-16 \*\*\*  
DESTIN\_SZJESZ11 0.5559641 0.0074629 74.497 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ01 -0.9790971 0.0071830 -136.308 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ02 -0.8746590 0.0060179 -145.342 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ03 0.5689062 0.0049105 115.855 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ04 0.4520963 0.0050302 89.876 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ05 -1.0249671 0.0067371 -152.137 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ06 -0.7451483 0.0062189 -119.819 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ07 -2.8453099 0.0287335 -99.024 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ08 -0.3372309 0.0058003 -58.141 < 2e-16 \*\*\*  
DESTIN\_SZJWSZ09 1.0505330 0.0045908 228.832 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ01 -0.2334836 0.0057970 -40.277 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ02 -0.5416148 0.0061432 -88.164 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ03 -0.8026495 0.0068745 -116.757 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ04 -1.2918594 0.0090197 -143.227 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ05 -0.4069101 0.0087812 -46.339 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ06 -2.5333101 0.0363215 -69.747 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ07 -0.6623343 0.0070761 -93.601 < 2e-16 \*\*\*  
DESTIN\_SZKLSZ08 -0.1408205 0.0054965 -25.620 < 2e-16 \*\*\*  
DESTIN\_SZLKSZ01 -1.2639235 0.0208254 -60.691 < 2e-16 \*\*\*  
DESTIN\_SZMDSZ01 -1.5655800 0.0202787 -77.203 < 2e-16 \*\*\*  
DESTIN\_SZMDSZ02 -0.9767682 0.0114687 -85.168 < 2e-16 \*\*\*  
DESTIN\_SZMDSZ03 -3.3328109 0.0254294 -131.061 < 2e-16 \*\*\*  
DESTIN\_SZMPSZ01 -0.4552859 0.0080666 -56.441 < 2e-16 \*\*\*  
DESTIN\_SZMPSZ02 -0.5386560 0.0064620 -83.358 < 2e-16 \*\*\*  
DESTIN\_SZMPSZ03 0.4952000 0.0052295 94.694 < 2e-16 \*\*\*  
DESTIN\_SZMUSZ02 -1.4434175 0.0202509 -71.277 < 2e-16 \*\*\*  
DESTIN\_SZNTSZ01 -2.9194067 0.0449654 -64.926 < 2e-16 \*\*\*  
DESTIN\_SZNTSZ02 -1.3780179 0.0112867 -122.092 < 2e-16 \*\*\*  
DESTIN\_SZNTSZ03 -0.5044699 0.0080449 -62.707 < 2e-16 \*\*\*  
DESTIN\_SZNTSZ05 -2.0017134 0.0258750 -77.361 < 2e-16 \*\*\*  
DESTIN\_SZNTSZ06 -3.8120537 0.0434271 -87.781 < 2e-16 \*\*\*  
DESTIN\_SZNVSZ01 -0.1071506 0.0051026 -20.999 < 2e-16 \*\*\*  
DESTIN\_SZNVSZ02 -0.0274710 0.0057611 -4.768 1.86e-06 \*\*\*  
DESTIN\_SZNVSZ03 0.1076352 0.0057909 18.587 < 2e-16 \*\*\*  
DESTIN\_SZNVSZ04 -1.2087250 0.0110438 -109.448 < 2e-16 \*\*\*  
DESTIN\_SZNVSZ05 -1.0058290 0.0092167 -109.131 < 2e-16 \*\*\*  
DESTIN\_SZPGSZ01 -1.2029931 0.0163170 -73.726 < 2e-16 \*\*\*  
DESTIN\_SZPGSZ02 -1.2878671 0.0074139 -173.709 < 2e-16 \*\*\*  
DESTIN\_SZPGSZ03 -0.1520894 0.0048629 -31.275 < 2e-16 \*\*\*  
DESTIN\_SZPGSZ04 -0.1985959 0.0050374 -39.424 < 2e-16 \*\*\*  
DESTIN\_SZPGSZ05 -1.5290983 0.0082617 -185.083 < 2e-16 \*\*\*  
DESTIN\_SZPLSZ01 -0.3567934 0.0074298 -48.022 < 2e-16 \*\*\*  
DESTIN\_SZPLSZ02 -1.7114351 0.0134462 -127.280 < 2e-16 \*\*\*  
DESTIN\_SZPLSZ03 -0.3241427 0.0098895 -32.776 < 2e-16 \*\*\*  
DESTIN\_SZPLSZ04 -1.7117196 0.0119003 -143.838 < 2e-16 \*\*\*  
DESTIN\_SZPLSZ05 -0.5086379 0.0120051 -42.368 < 2e-16 \*\*\*  
DESTIN\_SZPNSZ01 0.2026781 0.0068977 29.383 < 2e-16 \*\*\*  
DESTIN\_SZPNSZ02 0.8313754 0.0078544 105.848 < 2e-16 \*\*\*  
DESTIN\_SZPNSZ03 -0.4041254 0.0086586 -46.673 < 2e-16 \*\*\*  
DESTIN\_SZPNSZ04 1.5814539 0.0093641 168.885 < 2e-16 \*\*\*  
DESTIN\_SZPNSZ05 1.1823430 0.0129843 91.059 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ01 -1.1057553 0.0088197 -125.374 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ02 0.0895099 0.0056308 15.897 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ03 0.6921925 0.0043977 157.397 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ04 -0.2848336 0.0084725 -33.619 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ05 0.1744480 0.0053553 32.575 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ06 0.4279206 0.0058735 72.856 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ07 -1.5123108 0.0124303 -121.664 < 2e-16 \*\*\*  
DESTIN\_SZPRSZ08 -0.5650226 0.0068530 -82.449 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ01 -0.5952360 0.0090505 -65.769 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ02 -0.7728170 0.0078910 -97.937 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ03 -0.5066812 0.0073996 -68.474 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ04 -0.6398414 0.0075411 -84.847 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ05 -0.4354527 0.0069345 -62.795 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ06 -0.6597391 0.0071919 -91.733 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ07 -0.9392696 0.0112518 -83.477 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ08 0.4617774 0.0057011 80.998 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ09 -0.3174497 0.0065890 -48.178 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ10 0.1993449 0.0059923 33.267 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ11 0.2551535 0.0061885 41.230 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ12 -0.1662603 0.0086701 -19.176 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ13 0.5500978 0.0063091 87.192 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ14 0.5364435 0.0070157 76.463 < 2e-16 \*\*\*  
DESTIN\_SZQTSZ15 1.3611043 0.0081643 166.715 < 2e-16 \*\*\*  
DESTIN\_SZRCSZ01 -0.1034049 0.0076769 -13.470 < 2e-16 \*\*\*  
DESTIN\_SZRCSZ06 -1.0633902 0.0189846 -56.013 < 2e-16 \*\*\*  
DESTIN\_SZRVSZ01 -1.5486221 0.0165272 -93.701 < 2e-16 \*\*\*  
DESTIN\_SZRVSZ02 -2.4092611 0.0326906 -73.699 < 2e-16 \*\*\*  
DESTIN\_SZRVSZ03 -1.5172079 0.0139258 -108.950 < 2e-16 \*\*\*  
DESTIN\_SZRVSZ04 -1.1663615 0.0157430 -74.088 < 2e-16 \*\*\*  
DESTIN\_SZRVSZ05 -2.2404292 0.0281339 -79.634 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ01 -1.3783780 0.0096022 -143.549 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ02 -1.4445213 0.0081630 -176.959 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ03 0.5149906 0.0051663 99.683 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ04 0.2389086 0.0060765 39.317 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ05 -1.2737442 0.0082818 -153.801 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ06 -1.8683520 0.0227277 -82.206 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ07 -0.5993154 0.0184895 -32.414 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ08 0.8156302 0.0059840 136.302 < 2e-16 \*\*\*  
DESTIN\_SZSBSZ09 0.0900611 0.0057054 15.785 < 2e-16 \*\*\*  
DESTIN\_SZSESZ02 -0.6397704 0.0052491 -121.882 < 2e-16 \*\*\*  
DESTIN\_SZSESZ03 0.1714103 0.0042357 40.468 < 2e-16 \*\*\*  
DESTIN\_SZSESZ04 -1.0596175 0.0059865 -177.002 < 2e-16 \*\*\*  
DESTIN\_SZSESZ05 -0.8071891 0.0051229 -157.566 < 2e-16 \*\*\*  
DESTIN\_SZSESZ06 -0.5580934 0.0066216 -84.284 < 2e-16 \*\*\*  
DESTIN\_SZSESZ07 -3.1448863 0.0227788 -138.062 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ01 -0.1795225 0.0060127 -29.857 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ02 -0.2986570 0.0053561 -55.760 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ03 -0.4074671 0.0050609 -80.513 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ04 -0.1505164 0.0050931 -29.553 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ05 -1.9908372 0.0101448 -196.242 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ06 0.6715268 0.0041161 163.148 < 2e-16 \*\*\*  
DESTIN\_SZSGSZ07 -0.4494757 0.0055319 -81.252 < 2e-16 \*\*\*  
DESTIN\_SZSISZ01 -0.5517983 0.0261860 -21.072 < 2e-16 \*\*\*  
DESTIN\_SZSKSZ01 -0.4749154 0.0079257 -59.921 < 2e-16 \*\*\*  
DESTIN\_SZSKSZ02 0.9400302 0.0057218 164.290 < 2e-16 \*\*\*  
DESTIN\_SZSKSZ03 -0.2800377 0.0066081 -42.378 < 2e-16 \*\*\*  
DESTIN\_SZSKSZ04 -1.2570212 0.0145351 -86.482 < 2e-16 \*\*\*  
DESTIN\_SZSKSZ05 -0.2600474 0.0112800 -23.054 < 2e-16 \*\*\*  
DESTIN\_SZSLSZ01 -0.7775604 0.0085818 -90.606 < 2e-16 \*\*\*  
DESTIN\_SZSLSZ04 -0.8586515 0.0073142 -117.396 < 2e-16 \*\*\*  
DESTIN\_SZSRSZ01 -1.1370887 0.0142148 -79.993 < 2e-16 \*\*\*  
DESTIN\_SZTHSZ01 -4.3259988 0.0368554 -117.378 < 2e-16 \*\*\*  
DESTIN\_SZTHSZ03 -2.6632914 0.0252720 -105.385 < 2e-16 \*\*\*  
DESTIN\_SZTHSZ04 -3.1000906 0.0216372 -143.276 < 2e-16 \*\*\*  
DESTIN\_SZTHSZ06 -2.5952642 0.0156340 -166.001 < 2e-16 \*\*\*  
DESTIN\_SZTMSZ01 -0.2092828 0.0059257 -35.318 < 2e-16 \*\*\*  
DESTIN\_SZTMSZ02 1.8238139 0.0039155 465.798 < 2e-16 \*\*\*  
DESTIN\_SZTMSZ03 0.8518259 0.0043636 195.210 < 2e-16 \*\*\*  
DESTIN\_SZTMSZ04 1.0222812 0.0043466 235.191 < 2e-16 \*\*\*  
DESTIN\_SZTMSZ05 0.6323777 0.0060058 105.294 < 2e-16 \*\*\*  
DESTIN\_SZTNSZ01 -0.3336078 0.0074388 -44.847 < 2e-16 \*\*\*  
DESTIN\_SZTNSZ02 -1.0820469 0.0101689 -106.408 < 2e-16 \*\*\*  
DESTIN\_SZTNSZ03 -1.4186505 0.0119906 -118.313 < 2e-16 \*\*\*  
DESTIN\_SZTNSZ04 -0.3058199 0.0074743 -40.916 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ01 -0.4872299 0.0061571 -79.133 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ02 0.7158441 0.0041312 173.278 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ03 -0.4314229 0.0059917 -72.004 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ04 -1.5898245 0.0076083 -208.959 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ05 -1.0445550 0.0062363 -167.497 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ06 -0.4319582 0.0070100 -61.621 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ07 -2.1602303 0.0120352 -179.493 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ08 -1.1920493 0.0093083 -128.063 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ09 -0.2022481 0.0071137 -28.431 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ10 -1.2464793 0.0090124 -138.308 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ11 -0.0808445 0.0056019 -14.432 < 2e-16 \*\*\*  
DESTIN\_SZTPSZ12 -0.6784376 0.0066340 -102.267 < 2e-16 \*\*\*  
DESTIN\_SZTSSZ01 -1.5845062 0.0222086 -71.346 < 2e-16 \*\*\*  
DESTIN\_SZTSSZ02 -0.1886010 0.0146338 -12.888 < 2e-16 \*\*\*  
DESTIN\_SZTSSZ03 0.6525526 0.0092450 70.585 < 2e-16 \*\*\*  
DESTIN\_SZTSSZ04 0.5285464 0.0100182 52.759 < 2e-16 \*\*\*  
DESTIN\_SZTSSZ05 1.4670106 0.0104357 140.577 < 2e-16 \*\*\*  
DESTIN\_SZTSSZ06 2.5043588 0.0167444 149.564 < 2e-16 \*\*\*  
DESTIN\_SZWCSZ01 1.9787931 0.0054306 364.375 < 2e-16 \*\*\*  
DESTIN\_SZWCSZ02 -2.2593108 0.0127916 -176.624 < 2e-16 \*\*\*  
DESTIN\_SZWCSZ03 -3.1897655 0.0326927 -97.568 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ01 1.0476108 0.0044629 234.738 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ02 -1.3176990 0.0065894 -199.973 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ03 0.3432057 0.0052496 65.377 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ04 -0.7895927 0.0073392 -107.586 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ05 -0.8751665 0.0072946 -119.975 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ06 -0.2106221 0.0053027 -39.720 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ07 -1.6050834 0.0071754 -223.692 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ08 -0.5124717 0.0069223 -74.032 < 2e-16 \*\*\*  
DESTIN\_SZWDSZ09 0.3813542 0.0054697 69.721 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ01 0.0853753 0.0046572 18.332 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ02 -0.3227172 0.0057351 -56.271 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ03 -0.4151283 0.0066299 -62.615 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ04 -0.4637327 0.0058206 -79.671 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ05 -1.5888242 0.0111001 -143.136 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ06 -1.4606209 0.0107759 -135.545 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ07 -0.7839065 0.0144357 -54.304 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ08 0.6265412 0.0045504 137.691 < 2e-16 \*\*\*  
DESTIN\_SZYSSZ09 0.1520067 0.0048092 31.607 < 2e-16 \*\*\*  
log(DIST) -1.8468315 0.0004608 -4008.033 < 2e-16 \*\*\*  
---  
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1  
  
(Dispersion parameter for poisson family taken to be 1)  
  
 Null deviance: 47094011 on 14470 degrees of freedom  
Residual deviance: 10420261 on 13912 degrees of freedom  
AIC: 10510518  
  
Number of Fisher Scoring iterations: 7

|  |
| --- |
| Do it yourself |
| What statistical conclusion you can draw from the report above? |

Next, let us examine how well the proportion of variance in the dependent variable (i.e. TRIPS) that can be explained by the explanatory variables.

|  |
| --- |
| Do it yourself |
| Using the R-Squared function written earlier, compute the R-Squared of the Doubly-constrined Model. |

CalcRSquared(dbcSIM\_Poisson$data$TRIPS,  
 dbcSIM\_Poisson$fitted.values)

[1] 0.7001882

Notice that there is a relatively greater improvement in the R-Squared value.

## Model comparison

### Statistical measures

Another useful model performance measure for continuous dependent variable is [Root Mean Squared Error](https://towardsdatascience.com/what-does-rmse-really-mean-806b65f2e48e). In this sub-section, you will learn how to use [compare\_performance()](https://easystats.github.io/performance/reference/compare_performance.html) of [**performance**](https://easystats.github.io/performance/index.html) package

First of all, let us create a list called *model\_list* by using the code chunk below.

model\_list <- list(  
 Origin\_Constrained = orcSIM\_Poisson,  
 Doubly\_Constrained = dbcSIM\_Poisson)

Next, we will compute the RMSE of all the models in *model\_list* file by using the code chunk below.

compare\_performance(model\_list,  
 metrics = "RMSE")

# Comparison of Model Performance Indices  
  
Name | Model | RMSE  
-------------------------------------  
Origin\_Constrained | glm | 2613.236  
Doubly\_Constrained | glm | 1906.694

The print above reveals that doubly constrained SIM is the best model among the two SIMs because it has the smallest RMSE value of 1906.694.

### Visualising fitted values

In this section, you will learn how to visualise the observed values and the fitted values.

Firstly we will extract the fitted values from Origin-constrained Model by using the code chunk below.

df <- as.data.frame(orcSIM\_Poisson$fitted.values) %>%  
 round(digits = 0)

Next, we will append the fitted values into *inter\_zonal\_flow* data frame by using the code chunk below.

inter\_zonal\_flow <- inter\_zonal\_flow %>%  
 cbind(df) %>%  
 rename(orcTRIPS = "orcSIM\_Poisson.fitted.values")

|  |
| --- |
| Tip |
| Notice that rename() is used to rename the field name and the $ in the original field name has been replaced with an .. This is because R replaced $ with . during the cbind(). |

|  |
| --- |
| Do it yourself |
| Repeat the same step for Doubly Constrained Model (i.e. dbcSIM\_Poisson) |

df <- as.data.frame(dbcSIM\_Poisson$fitted.values) %>%  
 round(digits = 0)

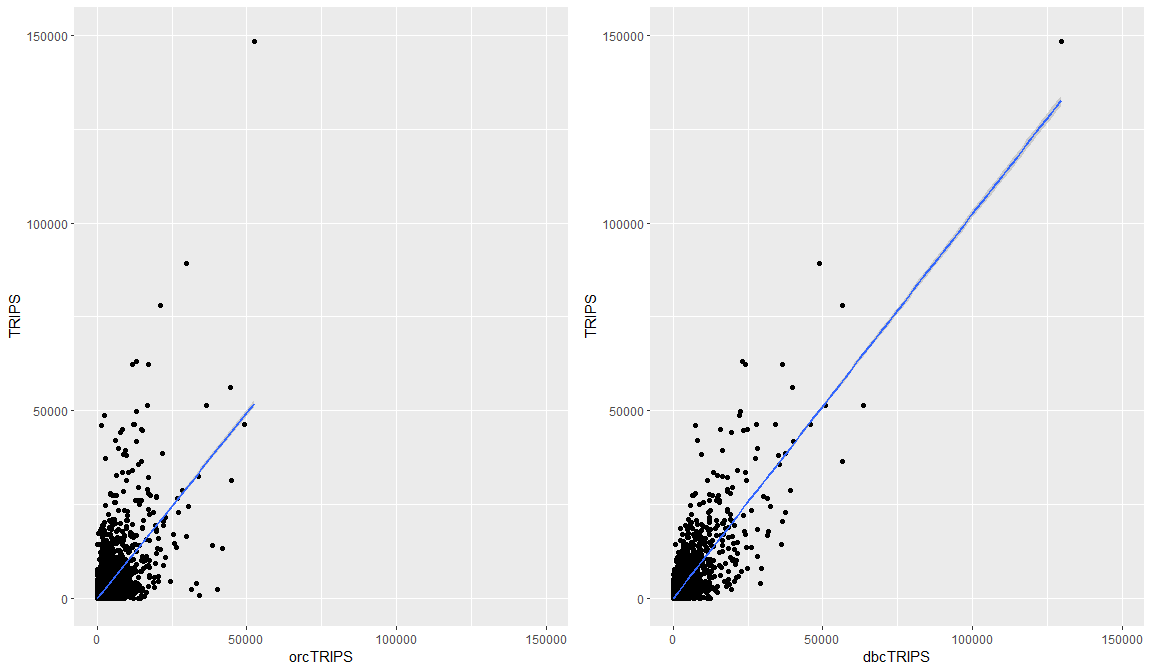
inter\_zonal\_flow <- inter\_zonal\_flow %>%  
 cbind(df) %>%  
 rename(dbcTRIPS = "dbcSIM\_Poisson.fitted.values")

Next, two scatterplots will be created by using [geom\_point()](https://ggplot2.tidyverse.org/reference/geom_point.html) and other appropriate functions of [**ggplot2**](https://ggplot2.tidyverse.org/) package.

orc\_p <- ggplot(data = inter\_zonal\_flow,  
 aes(x = orcTRIPS,  
 y = TRIPS)) +  
 geom\_point() +  
 geom\_smooth(method = lm) +  
 coord\_cartesian(xlim=c(0,150000),  
 ylim=c(0,150000))  
  
dbc\_p <- ggplot(data = inter\_zonal\_flow,  
 aes(x = dbcTRIPS,  
 y = TRIPS)) +  
 geom\_point() +  
 geom\_smooth(method = lm) +  
 coord\_cartesian(xlim=c(0,150000),  
 ylim=c(0,150000))

Now, we will put all the graphs into a single visual for better comparison by using the code chunk below.

ggarrange(orc\_p, dbc\_p,  
 ncol = 2,  
 nrow = 1)



|  |
| --- |
| Quiz |
| What observation can you draw from the figure above and what follow-up action will you take? |