



Tidy Time Series & Forecasting in R



1. Tidy time series tsibbles

robjhyndman.com/workshop2020

Outline

- 1 Time series data and tsibbles
- 2 Example: Australian prison population
- 3 Example: Australian pharmaceutical sales
- 4 Lab Session 1

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tsibble



tsibbledata



feasts



Sable

Time series data

- Four-yearly Olympic winning times
- Annual Google profits
- Quarterly Australian beer production
- Monthly rainfall
- Weekly retail sales
- Daily IBM stock prices
- Hourly electricity demand
- 5-minute freeway traffic counts
- Time-stamped stock transaction data

Class packages

```
# Data manipulation and plotting functions  
library(tidyverse)  
# Time series manipulation  
library(tsibble)  
# Forecasting functions  
library(fable)  
# Time series graphics and statistics  
library(feasts)  
# Tidy time series data  
library(tsibbledata)
```

tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
## # Key:      Country [263]
##   Year Country      GDP Imports Exports Population
##   <dbl> <fct>          <dbl>   <dbl>   <dbl>         <dbl>
## 1  1960 Afghanistan 5377777811.    7.02    4.13    8996351
## 2  1961 Afghanistan 5488888896.    8.10    4.45    9166764
## 3  1962 Afghanistan 5466666678.    9.35    4.88    9345868
## 4  1963 Afghanistan 7511111191.   16.9     9.17    9533954
## 5  1964 Afghanistan 8000000044.   18.1     8.89    9731361
## 6  1965 Afghanistan 10066666638.  21.4    11.3    9938414
## 7  1966 Afghanistan 13999999967.  18.6     8.57   10152331
## 8  1967 Afghanistan 16733333418.  14.2     6.77   10372630
## 9  1968 Afghanistan 13733333367.  15.2     8.90   10604346
## 10 1969 Afghanistan 14088888922.  15.0    10.1   10854428
## # ... with 15,140 more rows
```

tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
## # Key:      Country [263]
##   Year Country      GDP Imports Exports Population
##   Index <fct>      <dbl>   <dbl>   <dbl>         <dbl>
## 1  1960 Afghanistan 5377777811.    7.02    4.13    8996351
## 2  1961 Afghanistan 5488888896.    8.10    4.45    9166764
## 3  1962 Afghanistan 5466666678.    9.35    4.88    9345868
## 4  1963 Afghanistan 7511111191.   16.9     9.17    9533954
## 5  1964 Afghanistan 8000000044.   18.1     8.89    9731361
## 6  1965 Afghanistan 10066666638.  21.4    11.3    9938414
## 7  1966 Afghanistan 13999999967.  18.6     8.57   10152331
## 8  1967 Afghanistan 16733333418.  14.2     6.77   10372630
## 9  1968 Afghanistan 13733333367.  15.2     8.90   10604346
## 10 1969 Afghanistan 14088888922.  15.0    10.1   10854428
## # ... with 15,140 more rows
```


tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
```

```
## # Key:          Country [263]
```

```
##      Year Country      GDP Imports Exports Population
##      Index  Key      <dbl>   <dbl>   <dbl>         <dbl>
##  1  1960 Afghanistan 5377777811.    7.02    4.13    8996351
##  2  1961 Afghanistan 5488888896.    8.10    4.45    9166764
##  3  1962 Afghanistan 546666678.    9.35    4.88    9345868
##  4  1963 Afghanistan 7511111191.   16.9    9.17    9533954
##  5  1964 Afghanistan 8000000044.   18.1    8.89    9731361
##  6  1965 Afghanistan 1006666638.   21.4   11.3    9938414
##  7  1966 Afghanistan 1399999967.   18.6    8.57   10152331
##  8  1967 Afghanistan 1673333418.   14.2    6.77   10372630
##  9  1968 Afghanistan 1373333367.   15.2    8.90   10604346
## 10  1969 Afghanistan 1408888922.   15.0   10.1   10854428
## # ... with 15,140 more rows
```

tsibble objects

```
global_economy
```

```
## # A tsibble: 15,150 x 6 [1Y]
```

```
## # Key:      Country [263]
```

```
##      Year Country      GDP Imports Exports Population
```

```
##      Index  Key      Measured variables
```

```
## 1  1960 Afghanistan 5377777811.    7.02    4.13    8996351
```

```
## 2  1961 Afghanistan 5488888896.    8.10    4.45    9166764
```

```
## 3  1962 Afghanistan 5466666678.    9.35    4.88    9345868
```

```
## 4  1963 Afghanistan 7511111191.   16.9    9.17    9533954
```

```
## 5  1964 Afghanistan 8000000044.   18.1    8.89    9731361
```

```
## 6  1965 Afghanistan 10066666638.  21.4   11.3    9938414
```

```
## 7  1966 Afghanistan 13999999967.  18.6    8.57   10152331
```

```
## 8  1967 Afghanistan 16733333418.  14.2    6.77   10372630
```

```
## 9  1968 Afghanistan 13733333367.  15.2    8.90   10604346
```

```
## 10 1969 Afghanistan 14088888922.  15.0   10.1   10854428
```

```
## # ... with 15,140 more rows
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:           Region, State, Purpose [304]
##   Quarter Region   State Purpose   Trips
##   <qtr> <chr>      <chr> <chr>    <dbl>
## 1 1998 Q1 Adelaide SA      Business 135.
## 2 1998 Q2 Adelaide SA      Business 110.
## 3 1998 Q3 Adelaide SA      Business 166.
## 4 1998 Q4 Adelaide SA      Business 127.
## 5 1999 Q1 Adelaide SA      Business 137.
## 6 1999 Q2 Adelaide SA      Business 200.
## 7 1999 Q3 Adelaide SA      Business 169.
## 8 1999 Q4 Adelaide SA      Business 134.
## 9 2000 Q1 Adelaide SA      Business 154.
## 10 2000 Q2 Adelaide SA      Business 169.
## # ... with 24,310 more rows
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:           Region, State, Purpose [304]
##   Quarter Region State Purpose Trips
##   Index  <chr>    <chr> <chr>    <dbl>
## 1 1998 Q1 Adelaide SA      Business 135.
## 2 1998 Q2 Adelaide SA      Business 110.
## 3 1998 Q3 Adelaide SA      Business 166.
## 4 1998 Q4 Adelaide SA      Business 127.
## 5 1999 Q1 Adelaide SA      Business 137.
## 6 1999 Q2 Adelaide SA      Business 200.
## 7 1999 Q3 Adelaide SA      Business 169.
## 8 1999 Q4 Adelaide SA      Business 134.
## 9 2000 Q1 Adelaide SA      Business 154.
## 10 2000 Q2 Adelaide SA      Business 169.
## # ... with 24,310 more rows
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region  State Purpose  Trips
##   Index      Keys      <dbl>
## 1 1998 Q1 Adelaide SA      Business 135.
## 2 1998 Q2 Adelaide SA      Business 110.
## 3 1998 Q3 Adelaide SA      Business 166.
## 4 1998 Q4 Adelaide SA      Business 127.
## 5 1999 Q1 Adelaide SA      Business 137.
## 6 1999 Q2 Adelaide SA      Business 200.
## 7 1999 Q3 Adelaide SA      Business 169.
## 8 1999 Q4 Adelaide SA      Business 134.
## 9 2000 Q1 Adelaide SA      Business 154.
## 10 2000 Q2 Adelaide SA      Business 169.
## # ... with 24,310 more rows
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
```

```
## # Key:           Region, State, Purpose [304]
```

```
##   Quarter Region State Purpose Trips
```

```
##   Index      Keys      Measure
```

```
## 1 1998 Q1 Adelaide SA      Business 135.
```

```
## 2 1998 Q2 Adelaide SA      Business 110.
```

```
## 3 1998 Q3 Adelaide SA      Business 166.
```

```
## 4 1998 Q4 Adelaide SA      Business 127.
```

```
## 5 1999 Q1 Adelaide SA      Business 137.
```

```
## 6 1999 Q2 Adelaide SA      Business 200.
```

```
## 7 1999 Q3 Adelaide SA      Business 169.
```

```
## 8 1999 Q4 Adelaide SA      Business 134.
```

```
## 9 2000 Q1 Adelaide SA      Business 154.
```

```
## 10 2000 Q2 Adelaide SA      Business 169.
```

```
## # ... with 24,310 more rows
```

tsibble objects

```
tourism
```

```
## # A tsibble: 24,320 x 5 [1Q]
## # Key:      Region, State, Purpose [304]
##   Quarter Region State Purpose Trips
##   Index      Keys          Measure
## 1 1998 Q1 Adelaide SA      Business 135.
## 2 1998 Q2 Adelaide SA      Business 110.
## 3 1998 Q3 Adelaide SA      Business 166.
## 4 1998 Q4 Adelaide SA      Business 127.
## 5 1999 Q1 Adelaide SA      Business 137.
## 6 1999 Q2 Adelaide SA      Business 200.
## 7 1999 Q3 Adelaide SA      Business 169.
## 8 1999 Q4 Adelaide SA      Business 134.
## 9 2000 Q1 Adelaide SA      Business 154.
## 10 2000 Q2 Adelaide SA      Business 169.
## # ... with 24,310 more rows
```

Domestic visitor
nights in thousands
by state/region and
purpose.

tsibble objects

- A `tsibble` allows storage and manipulation of multiple time series in R.
- It contains:
 - ▶ An index: time information about the observation
 - ▶ Measured variable(s): numbers of interest
 - ▶ Key variable(s): optional unique identifiers for each series
- It works with tidyverse functions.

The tsibble index

Example

```
mydata <- tsibble(year = 2012:2016,  
  y = c(123,39,78,52,110), index = year)  
mydata
```

```
## # A tsibble: 5 x 2 [1Y]  
##   year      y  
##   <int> <dbl>  
## 1  2012    123  
## 2  2013     39  
## 3  2014     78  
## 4  2015     52  
## 5  2016    110
```

The tsibble index

For observations more frequent than once per year, we need to use a time class function on the index.

```
z
```

```
## # A tibble: 5 x 2
##   Month      Observation
##   <chr>         <dbl>
## 1 2019 Jan           50
## 2 2019 Feb           23
## 3 2019 Mar           34
## 4 2019 Apr           30
## 5 2019 May           25
```

The tsibble index

For observations more frequent than once per year, we need to use a time class function on the index.

```
z %>%  
  mutate(Month = yearmonth(Month)) %>%  
  as_tsibble(index = Month)
```

```
## # A tsibble: 5 x 2 [1M]  
##       Month Observation  
##       <mth>         <dbl>  
## 1 2019 Jan           50  
## 2 2019 Feb           23  
## 3 2019 Mar           34  
## 4 2019 Apr           30  
## 5 2019 May           25
```

The tsibble index

Common time index variables can be created with these functions:

Frequency	Function
Annual	<code>start:end</code>
Quarterly	<code>yearquarter()</code>
Monthly	<code>yearmonth()</code>
Weekly	<code>yearweek()</code>
Daily	<code>as_date()</code> , <code>ymd()</code>
Sub-daily	<code>as_datetime()</code>

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Australian prison population



Create a tsibble from a csv

date	state	gender	legal	indigenous	count
2005-03-01	ACT	Female	Remanded	ATSI	0
2005-03-01	ACT	Female	Remanded	Other	2
2005-03-01	ACT	Female	Sentenced	ATSI	0
2005-03-01	ACT	Female	Sentenced	Other	0
2005-03-01	ACT	Male	Remanded	ATSI	7
2005-03-01	ACT	Male	Remanded	Other	58
2005-03-01	ACT	Male	Sentenced	ATSI	0
2005-03-01	ACT	Male	Sentenced	Other	0
2005-03-01	NSW	Female	Remanded	ATSI	51
2005-03-01	NSW	Female	Remanded	Other	131
2005-03-01	NSW	Female	Sentenced	ATSI	0
2005-03-01	NSW	Female	Sentenced	Other	10
2005-03-01	NSW	Male	Remanded	ATSI	255

Read a csv file and convert to a tibble

```
prison <- readr::read_csv("prison_population.csv")
```

```
## # A tibble: 3,072 x 6
```

```
##   date          state gender legal      indigenous count
##   <date>        <chr> <chr>  <chr>    <chr>          <dbl>
## 1 2005-03-01 ACT     Female Remanded ATSI            0
## 2 2005-03-01 ACT     Female Remanded Other          2
## 3 2005-03-01 ACT     Female Sentenced ATSI            0
## 4 2005-03-01 ACT     Female Sentenced Other          0
## 5 2005-03-01 ACT     Male   Remanded ATSI            7
## 6 2005-03-01 ACT     Male   Remanded Other         58
## 7 2005-03-01 ACT     Male   Sentenced ATSI            0
## 8 2005-03-01 ACT     Male   Sentenced Other          0
## 9 2005-03-01 NSW     Female Remanded ATSI           51
##10 2005-03-01 NSW     Female Remanded Other        131
## # ... with 3,062 more rows
```


Read a csv file and convert to a tibble

```
prison <- readr::read_csv("prison_population.csv") %>%  
  mutate(Quarter = yearquarter(date))
```

```
## # A tibble: 3,072 x 7
```

##	date	state	gender	legal	indigenous	count	Quarter
##	<date>	<chr>	<chr>	<chr>	<chr>	<dbl>	<qtr>
##	1 2005-03-01	ACT	Female	Rema~	ATSI	0	2005 Q1
##	2 2005-03-01	ACT	Female	Rema~	Other	2	2005 Q1
##	3 2005-03-01	ACT	Female	Sent~	ATSI	0	2005 Q1
##	4 2005-03-01	ACT	Female	Sent~	Other	0	2005 Q1
##	5 2005-03-01	ACT	Male	Rema~	ATSI	7	2005 Q1
##	6 2005-03-01	ACT	Male	Rema~	Other	58	2005 Q1
##	7 2005-03-01	ACT	Male	Sent~	ATSI	0	2005 Q1
##	8 2005-03-01	ACT	Male	Sent~	Other	0	2005 Q1
##	9 2005-03-01	NSW	Female	Rema~	ATSI	51	2005 Q1
##	10 2005-03-01	NSW	Female	Rema~	Other	131	2005 Q1
##	# ... with 3,062 more rows						

Read a csv file and convert to a tibble

```
prison <- readr::read_csv("prison_population.csv") %>%  
  mutate(Quarter = yearquarter(date)) %>%  
  select(-date)
```

```
## # A tibble: 3,072 x 6
```

	state	gender	legal	indigenous	count	Quarter
	<chr>	<chr>	<chr>	<chr>	<dbl>	<qtr>
## 1	ACT	Female	Remanded	ATSI	0	2005 Q1
## 2	ACT	Female	Remanded	Other	2	2005 Q1
## 3	ACT	Female	Sentenced	ATSI	0	2005 Q1
## 4	ACT	Female	Sentenced	Other	0	2005 Q1
## 5	ACT	Male	Remanded	ATSI	7	2005 Q1
## 6	ACT	Male	Remanded	Other	58	2005 Q1
## 7	ACT	Male	Sentenced	ATSI	0	2005 Q1
## 8	ACT	Male	Sentenced	Other	0	2005 Q1
## 9	NSW	Female	Remanded	ATSI	51	2005 Q1
## 10	NSW	Female	Remanded	Other	131	2005 Q1

```
## # with 3,062 more rows
```

Read a csv file and convert to a tsibble

```
prison <- readr::read_csv("prison_population.csv") %>%  
  mutate(Quarter = yearquarter(date)) %>%  
  select(-date) %>%  
  as_tsibble(index=Quarter,  
    key=c(state, gender, legal, indigenous))
```

```
## # A tsibble: 3,072 x 6 [1Q]  
## # Key:      state, gender, legal, indigenous [64]  
##   state gender legal   indigenous count Quarter  
##   <chr> <chr>  <chr>    <chr>      <dbl>   <qtr>  
## 1 ACT   Female Remanded ATSI         0 2005 Q1  
## 2 ACT   Female Remanded ATSI         1 2005 Q2  
## 3 ACT   Female Remanded ATSI         0 2005 Q3  
## 4 ACT   Female Remanded ATSI         0 2005 Q4  
## 5 ACT   Female Remanded ATSI         1 2006 Q1  
## 6 ACT   Female Remanded ATSI         1 2006 Q2  
## 7 ACT   Female Remanded ATSI         1 2006 Q3  
## 8 ACT   Female Remanded ATSI         0 2006 Q4
```

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Australian Pharmaceutical Benefits Scheme



Australian Pharmaceutical Benefits Scheme

The **Pharmaceutical Benefits Scheme** (PBS) is the Australian government drugs subsidy scheme.

Australian Pharmaceutical Benefits Scheme

The **Pharmaceutical Benefits Scheme** (PBS) is the Australian government drugs subsidy scheme.

- Many drugs bought from pharmacies are subsidised to allow more equitable access to modern drugs.
- The cost to government is determined by the number and types of drugs purchased. Currently nearly 1% of GDP.
- The total cost is budgeted based on forecasts of drug usage.
- Costs are disaggregated by drug type (ATC1 x15 / ATC2 84), concession category (x2) and patient type (x2), giving $84 \times 2 \times 2 = 336$ time series.

Working with tibble objects

PBS

```
## # A tibble: 65,219 x 9 [1M]
## # Key:      Concession, Type, ATC1, ATC2 [336]
##           Month Concession Type  ATC1  ATC1_desc ATC2
##           <mth> <chr>      <chr> <chr> <chr>      <chr>
##  1  1991 Jul Concessio~ Co-p~ A      Alimenta~ A01
##  2  1991 Aug Concessio~ Co-p~ A      Alimenta~ A01
##  3  1991 Sep Concessio~ Co-p~ A      Alimenta~ A01
##  4  1991 Oct Concessio~ Co-p~ A      Alimenta~ A01
##  5  1991 Nov Concessio~ Co-p~ A      Alimenta~ A01
##  6  1991 Dec Concessio~ Co-p~ A      Alimenta~ A01
##  7  1992 Jan Concessio~ Co-p~ A      Alimenta~ A01
##  8  1992 Feb Concessio~ Co-p~ A      Alimenta~ A01
##  9  1992 Mar Concessio~ Co-p~ A      Alimenta~ A01
## 10  1992 Apr Concessio~ Co-p~ A      Alimenta~ A01
## # ... with 65,209 more rows, and 3 more variables:
## #   ATC2_desc <chr>, Scripts <dbl>, Cost <dbl>
```


Working with tsibble objects

We can use the `filter()` function to select rows.

```
PBS %>%
```

```
  filter(ATC2=="A10")
```

```
## # A tsibble: 816 x 9 [1M]
```

```
## # Key:      Concession, Type, ATC1, ATC2 [4]
```

##		Month	Concession	Type	ATC1	ATC1_desc	ATC2
##		<mth>	<chr>	<chr>	<chr>	<chr>	<chr>
##	1	1991 Jul	Concessio~	Co-p~	A	Alimenta~	A10
##	2	1991 Aug	Concessio~	Co-p~	A	Alimenta~	A10
##	3	1991 Sep	Concessio~	Co-p~	A	Alimenta~	A10
##	4	1991 Oct	Concessio~	Co-p~	A	Alimenta~	A10
##	5	1991 Nov	Concessio~	Co-p~	A	Alimenta~	A10
##	6	1991 Dec	Concessio~	Co-p~	A	Alimenta~	A10
##	7	1992 Jan	Concessio~	Co-p~	A	Alimenta~	A10
##	8	1992 Feb	Concessio~	Co-p~	A	Alimenta~	A10
##	9	1992 Mar	Concessio~	Co-p~	A	Alimenta~	A10
##	10	1992 Apr	Concessio~	Co-p~	A	Alimenta~	A10

```
## # with 806 more rows and 2 more variables:
```

Working with `tsibble` objects

We can use the `select()` function to select columns.

```
PBS %>%  
  filter(ATC2=="A10") %>%  
  select(Cost)
```

Selecting index: "Month"

Error: The result is not a valid tsibble.

Do you need `as_tibble()` to work with data frame?

Working with tsibble objects

We can use the `select()` function to select columns.

```
PBS %>%  
  filter(ATC2=="A10") %>%  
  select(Month, Concession, Type, Cost)
```

```
## # A tsibble: 816 x 4 [1M]  
## # Key:      Concession, Type [4]  
##      Month Concession  Type          Cost  
##      <mtm> <chr>      <chr>          <dbl>  
##  1 1991 Jul Concessional Co-payments 2092878  
##  2 1991 Aug Concessional Co-payments 1795733  
##  3 1991 Sep Concessional Co-payments 1777231  
##  4 1991 Oct Concessional Co-payments 1848507  
##  5 1991 Nov Concessional Co-payments 1686458  
##  6 1991 Dec Concessional Co-payments 1843079  
##  7 1992 Jan Concessional Co-payments 1564702  
##  8 1992 Feb Concessional Co-payments 1732508  
##  9 1992 Mar Concessional Co-payments 2046102  
## 10 1992 Apr Concessional Co-payments 2225877
```

Working with tsibble objects

We can use the `summarise()` function to summarise over keys.

```
PBS %>%  
  filter(ATC2=="A10") %>%  
  select(Month, Concession, Type, Cost) %>%  
  summarise(total_cost = sum(Cost))
```

```
## # A tsibble: 204 x 2 [1M]  
##       Month total_cost  
##       <mth>      <dbl>  
## 1 1991 Jul      3526591  
## 2 1991 Aug      3180891  
## 3 1991 Sep      3252221  
## 4 1991 Oct      3611003  
## 5 1991 Nov      3565869  
## 6 1991 Dec      4306371  
## 7 1992 Jan      5088335  
## 8 1992 Feb      2814520  
## 9 1992 Mar      2985811  
## 10 1992 Apr      3204780
```

Working with tsibble objects

We can use the `mutate()` function to create new variables.

```
PBS %>%  
  filter(ATC2=="A10") %>%  
  select(Month, Concession, Type, Cost) %>%  
  summarise(total_cost = sum(Cost)) %>%  
  mutate(total_cost = total_cost/1e6)
```

```
## # A tsibble: 204 x 2 [1M]
```

```
##       Month total_cost
```

```
##       <mth>      <dbl>
```

```
##  1 1991 Jul       3.53
```

```
##  2 1991 Aug       3.18
```

```
##  3 1991 Sep       3.25
```

```
##  4 1991 Oct       3.61
```

```
##  5 1991 Nov       3.57
```

```
##  6 1991 Dec       4.31
```

```
##  7 1992 Jan       5.09
```

```
##  8 1992 Feb       2.81
```

```
##  9 1992 Mar       2.80
```

Working with tsibble objects

We can use the `mutate()` function to create new variables.

```
PBS %>%  
  filter(ATC2=="A10") %>%  
  select(Month, Concession, Type, Cost) %>%  
  summarise(total_cost = sum(Cost)) %>%  
  mutate(total_cost = total_cost/1e6) -> a10
```

```
## # A tsibble: 204 x 2 [1M]
```

```
##       Month total_cost
```

```
##       <mtm>      <dbl>
```

```
##  1 1991 Jul      3.53
```

```
##  2 1991 Aug      3.18
```

```
##  3 1991 Sep      3.25
```

```
##  4 1991 Oct      3.61
```

```
##  5 1991 Nov      3.57
```

```
##  6 1991 Dec      4.31
```

```
##  7 1992 Jan      5.09
```

```
##  8 1992 Feb      2.81
```

```
##  9 1992 Mar      2.80
```

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Lab Session 1

- 1 Download `tourism.xlsx` from <http://robjhyndman.com/data/tourism.xlsx>, and read it into R using `read_excel()` from the `readxl` package.
- 2 Create a `tsibble` which is identical to the `tourism` `tsibble` from the `tsibble` package.
- 3 Find what combination of `Region` and `Purpose` had the maximum number of overnight trips on average.
- 4 Create a new `tsibble` which combines the `Purposes` and `Regions`, and just has total trips by `State`.