# Modeling travel behavior
Whether weather matters
A journey on transport and mobility research

Mario Cools

- Introduction

- Weather
  - Impact on traffic volumes
  - Impact on activity-travel behavior

- Weather forecasts

- Modeling travel behavior

Key research question:

"Do meteorological events influence travel behavior?"

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TRAVEL MARKET

Needs
Activities
Travel patterns
Space
Time
Time Arrangement
Spatial context

TRANSPORT MARKET

Transport patterns
Persons and Goods
Modalities
Services
Transport modes

TRAFFIC MARKET

Traffic patterns
Design
Infrastructure
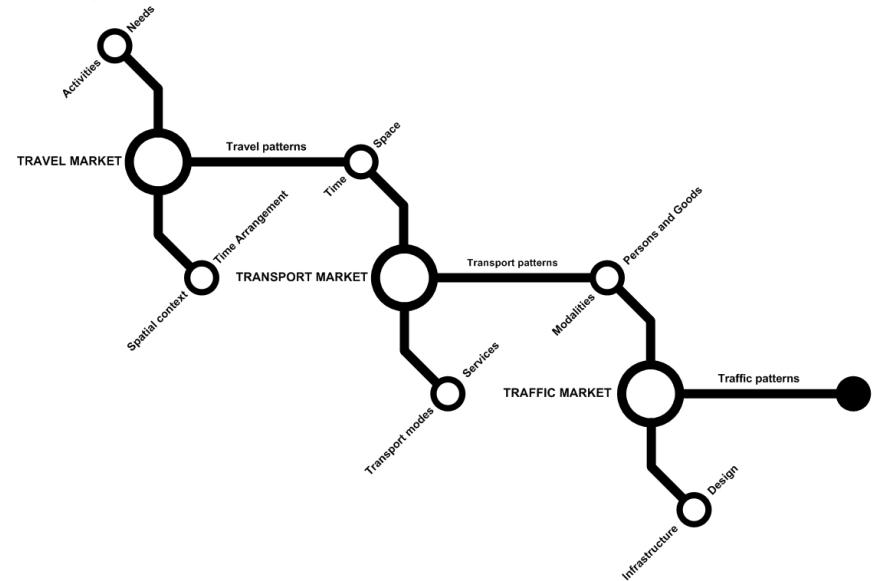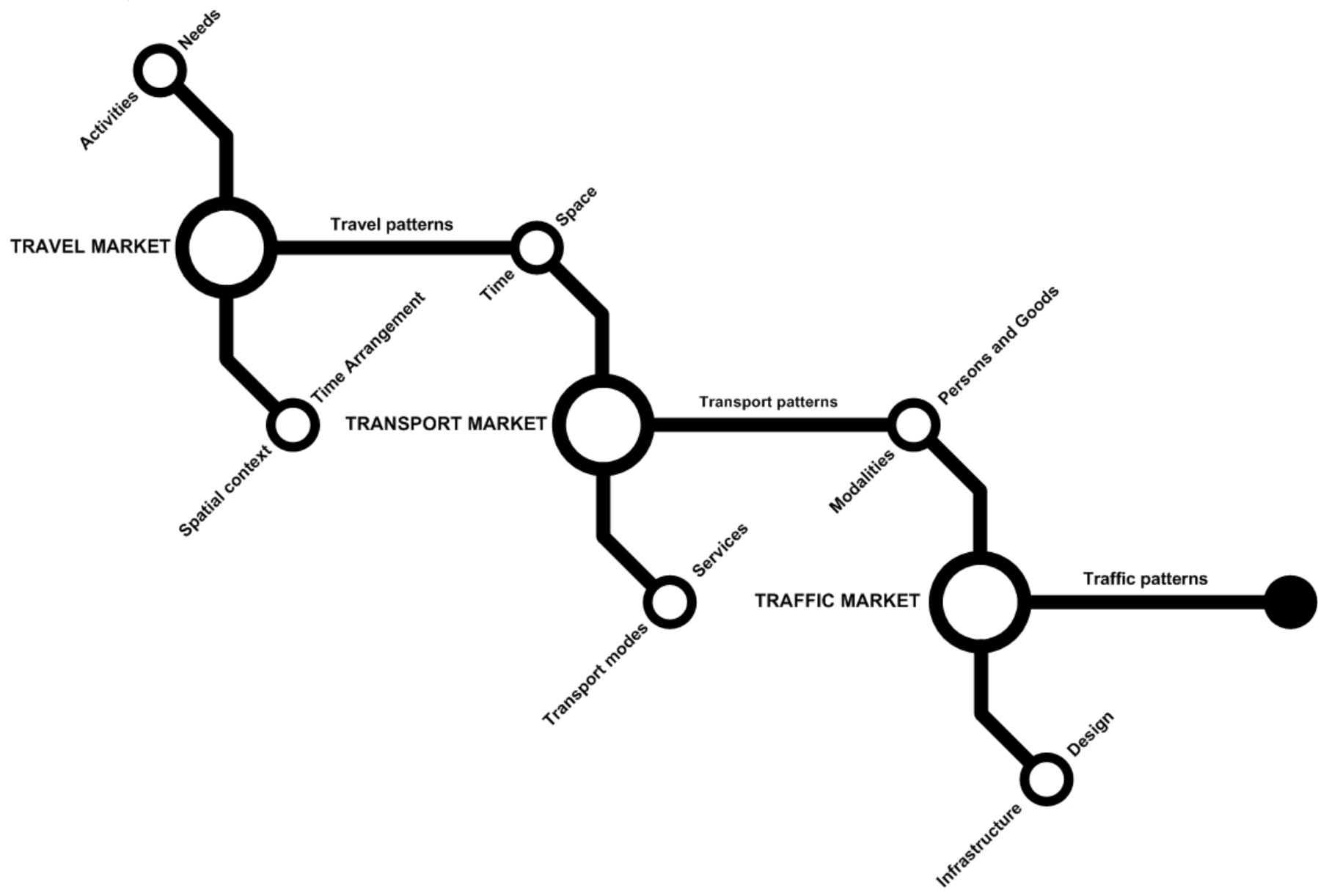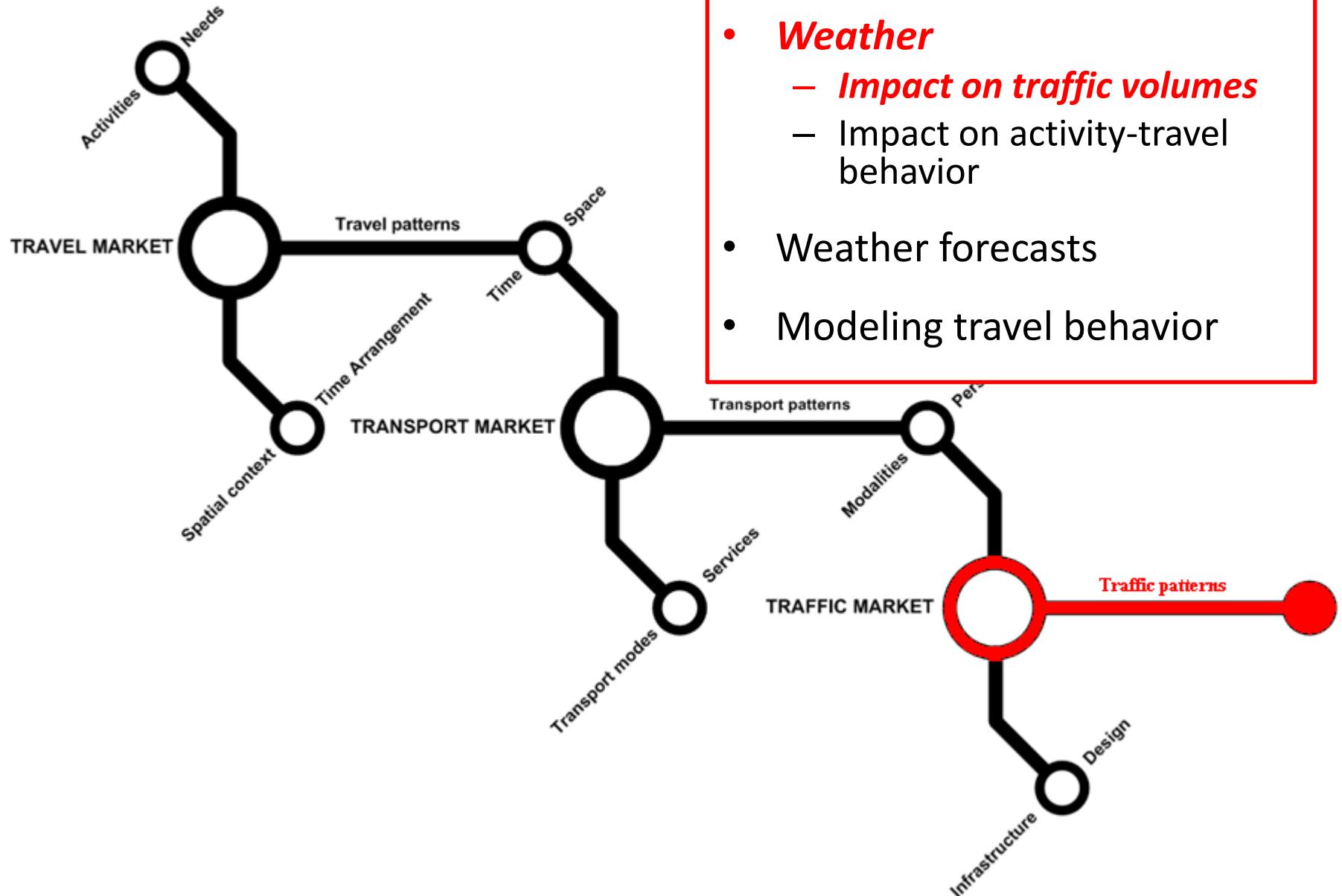
- Introduction

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- Weather forecasts

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- Traffic intensity data

- Weather data

- Temporal effects

Methodology
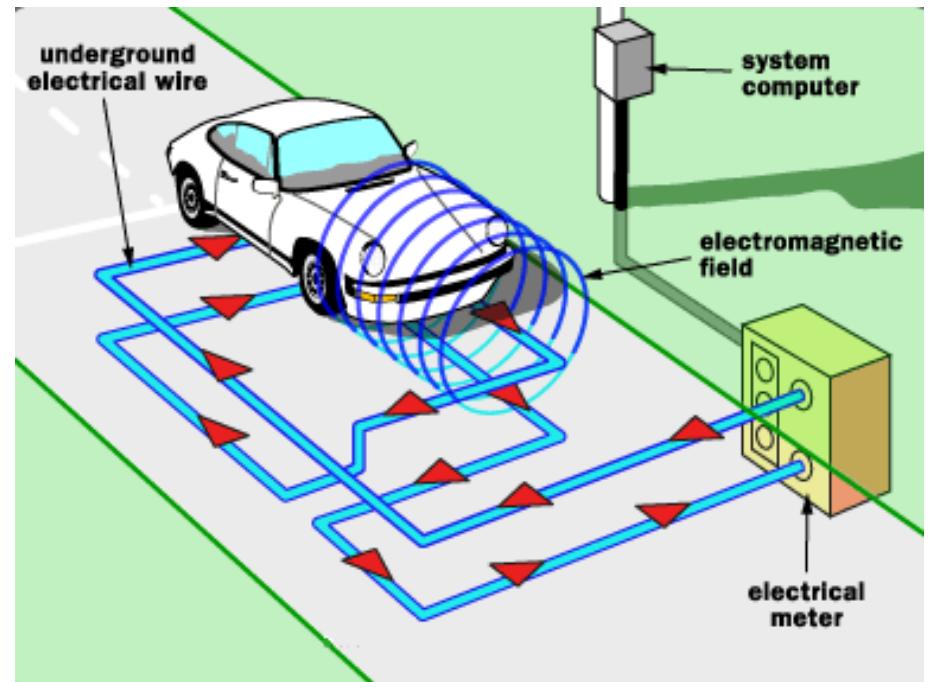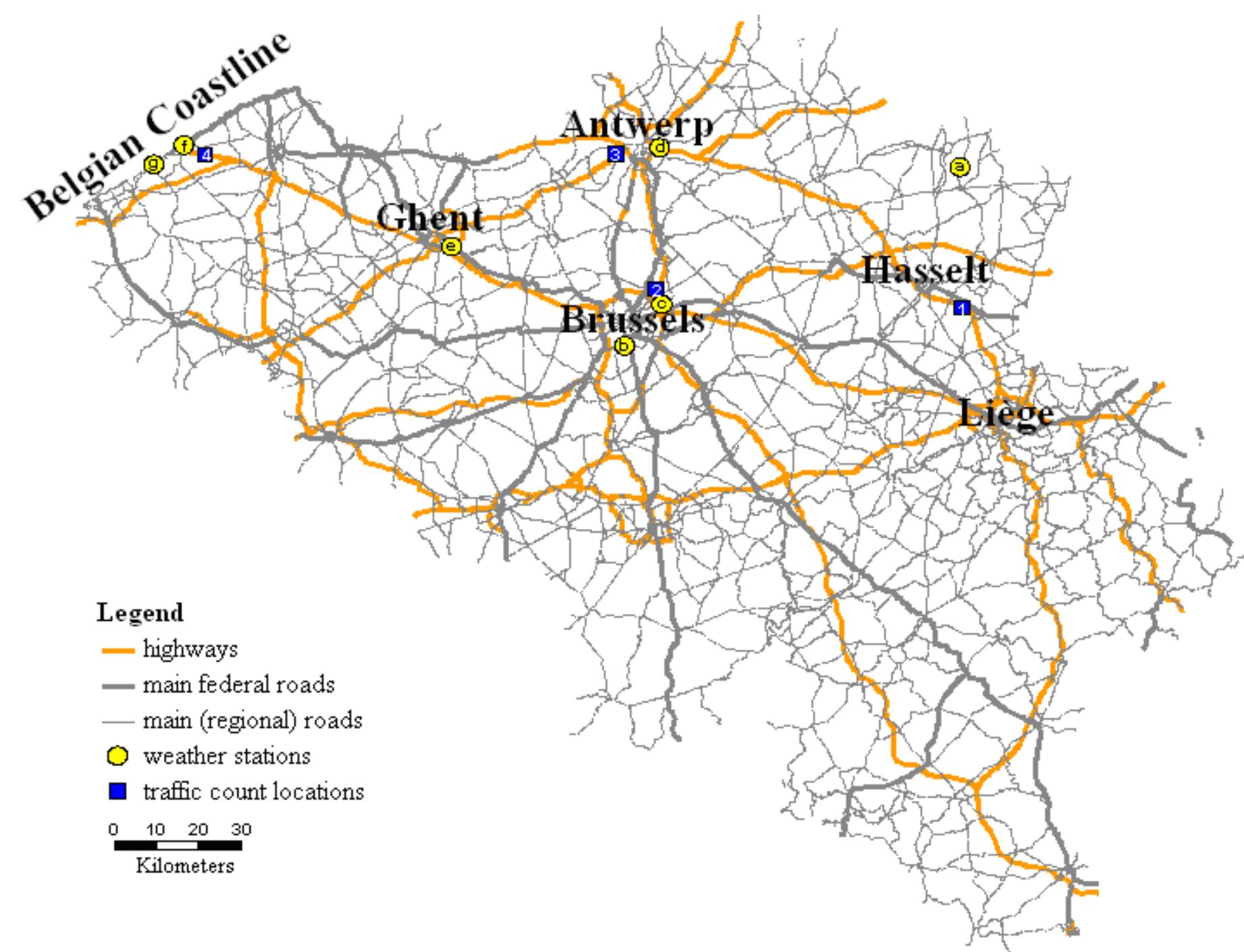
- Analysis: multiple linear regression
  - Equation: $Y_i = \beta_0 + \beta_1 X_{i,1} + \beta_2 X_{i,2} + ... + \beta_{p-1} X_{i,p-1} + \varepsilon_i$
  - Dependent variable: daily traffic counts
  - HAC-estimation
    $\rightarrow$ Periodicities in travel behaviour

Periodicities (spectral analysis)
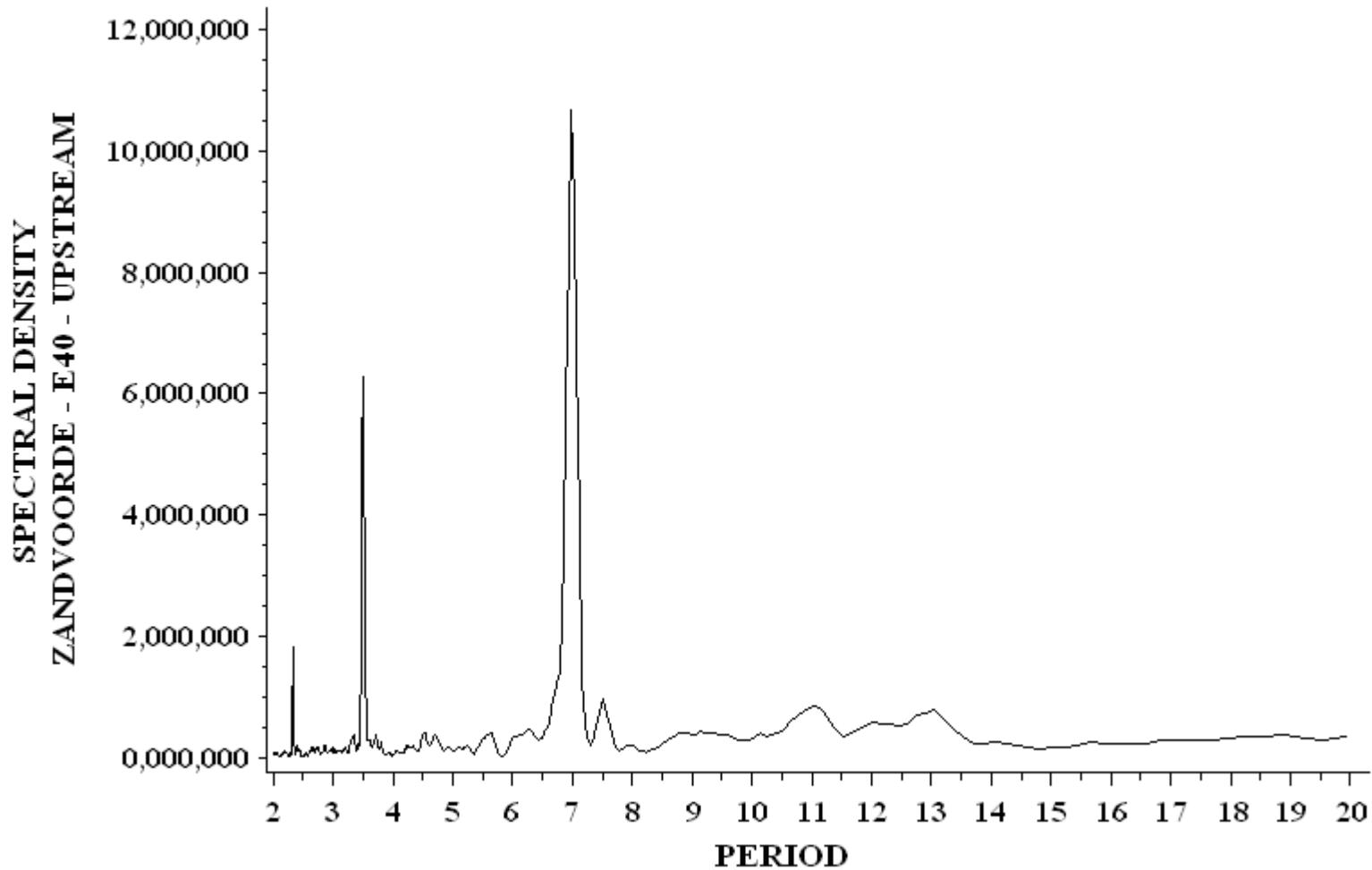
Group Means of Traffic Intensity by Presence of Weather Condition

Presence weather condition		Down Hasselt	Up Hasselt	Down Brussels	Up Brussels	Down Antwerp	Up Antwerp	Down Seashore	Up Seashore
Hail	Yes	18642	18273	57068	53830	51759	48665	11519	11707
	No	18173	17984	53382	50439	52260	46934	12902	13210
Thunder-storm	Yes	18791	18457	52225	49770	48350	44737	13339	13756
	No	18135	17953	53588	50599	52467	47103	12859	13161
Snow	Yes	17045	16765	51313	47745	50737	44548	11080	11188
	No	18267	18078	53615	50699	52319	47091	12933	13245

Parameter Estimates (HAC) for Weather Effects

Weather condition	Estimate	Standard Error	T-value	P-value	VIF
1. Location-specific model for downstream traffic in Hasselt					
Precipitation	-3.0	1.3	-2.33	0.020	1.22
Cloudiness (Mean)	-57.3	28.6	-2.01	0.045	1.30
Temperature (Max)	84.2	8.1	10.40	<0.001	1.33
Wind speed (Max)	-55.0	23.1	-2.38	0.018	1.15
2. Location-specific model for upstream traffic in Hasselt					
Precipitation	-2.9	1.3	-2.20	0.028	1.22
Cloudiness (Mean)	-55.4	26.7	-2.08	0.038	1.30
Temperature (Max)	84.0	7.4	11.42	<0.001	1.33
Wind speed (Max)	-66.2	21.3	-3.11	0.002	1.15

Results: location-specific models

Parameter Estimates (HAC) for Weather Effects

Weather condition	Estimate	Standard Error	T-value	P-value	VIF
3. Location-specific model for downstream traffic in Brussels					
Hail	2085.7	804.2	2.59	0.010	1.06
Snowfall	-2358.4	1077.0	-2.19	0.029	1.19
Precipitation	-13.4	3.9	-3.43	0.001	1.27
Temperature (Max)	106.7	26.9	3.96	<0.001	1.97
Wind speed (Max)	-170.1	59.7	-2.85	0.005	1.20
Sunshine duration	1.5	0.7	-2.08	0.038	1.68
4. Location-specific model for upstream traffic in Brussels					
Hail	2020.1	805.9	2.51	0.012	1.06
Snowfall	-3049.8	1025.2	-2.97	0.003	1.19
Precipitation	-11.6	3.5	-3.35	0.001	1.27
Temperature (Max)	93.3	25.8	3.62	<0.001	1.97
Wind speed (Max)	-126.4	54.6	-2.32	0.021	1.20
Sunshine duration	1.9	0.7	2.78	0.006	1.68

Parameter Estimates (HAC) for Weather Effects

Weather condition	Estimate	Standard Error	T-value	P-value	VIF
5. Location-specific model for downstream traffic in Antwerp					
Precipitation	-16.8	4.1	-4.08	<0.001	1.15
Temperature (Max)	161.3	30.4	5.31	<0.001	1.19
Wind speed (Max)	-202.9	70.9	-2.86	0.004	1.13
6. Location-specific model for upstream traffic in Antwerp					
Hail	3927.1	1144.3	3.43	0.001	1.07
Precipitation	-24.3	6.4	-3.78	<0.001	1.22
Temperature (Max)	140.0	45.6	3.07	0.002	1.79
Wind speed (Max)	-332.9	104.3	-3.19	0.002	1.19
Sunshine duration	4.7	1.2	3.85	<0.001	1.68
Visibility (<500m, Dum)	-3266.9	822.3	-3.97	<0.001	1.08

Results: location-specific models

Parameter Estimates (HAC) for Weather Effects

Weather condition	Estimate	Standard Error	T-value	P-value	VIF
7. Location-specific model for downstream traffic in seashore area					
Precipitation (Dum)	-437.2	89.1	-4.91	<0.001	1.50
Cloudiness (Mean)	-152.1	21.2	-7.19	<0.001	1.40
Temperature (Max)	129.4	7.3	17.67	<0.001	1.26
Wind speed (Max)	-49.3	13.9	-3.56	<0.001	1.22
Visibility (<200m, Dum)	615.0	278.6	2.21	0.028	1.03
8. Location-specific model for upstream traffic in seashore area					
Precipitation (Dum)	-308.1	105.9	-2.91	0.004	1.53
Cloudiness (Mean)	-217.2	26.5	-8.20	<0.001	1.41
Temperature (Max)	148.5	8.7	17.01	<0.001	1.26
Wind speed (Max)	-62.3	17.0	-3.66	<0.001	1.24
Visibility (<200m, Dum)	642.5	220.3	2.92	0.004	1.05

Results: overall model

Parameter estimates for Overall Traffic Intensity Model

Weather condition	Estimate	Weather condition	Estimate
General estimates			
Hail	3.385	Cloudiness	-0.427
Snowfall	-4.154	Wind speed (Max)	-0.425
Precipitation	-0.023	Sunshine duration	0.003
Location specific estimates			
Temperature (Downstream Hasselt)	0.340	Temperature (Downstream Antwerp)	0.182
Temperature (Upstream Hasselt)	0.346	Temperature (Upstream Antwerp)	0.399
Temperature (Downstream Brussels)	0.154	Temperature (Downstream Seashore)	0.983
Temperature (Upstream Brussels)	0.172	Temperature (Upstream Seashore)	1.131

Results: summary

Summary of Relationships between Weather Conditions and Traffic Intensity

Weather conditions	Down Hasselt	Up Hasselt	Down Brussels	Up Brussels	Down Antwerp	Up Antwerp	Down Seashore	Up Seashore	Overall model
Hail	0	0	+	+	0	+	0	0	+
Snowfall	0	0	-	-	0	0	0	0	-
Precipitation	-	-	-	-	-	-	-	-	-
Temperature (Max)	+	+	+	+	+	+	+	+	+
Wind speed (Max)	-	-	-	-	-	-	-	-	-
Sunshine duration	0	0	+	+	0	+	0	0	+
Reduced visibility	0	0	0	0	0	-	+	+	0
Cloudiness (Mean)	-	-	0	0	0	0	-	-	-
R-square	0.79	0.69	0.86	0.85	0.75	0.51	0.65	0.67	0.70

Conclusions

- Heterogeneity between different traffic count locations
- Homogeneity between upstream and downstream traffic at a certain location
- Diminishing factors:
  - precipitation, cloudiness, and wind speed
- Increasing factors:
  - maximum temperature, sunshine duration and hail
- Pathways for further research

- Introduction

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  - ***Impact on activity-travel behavior***

- Weather forecasts

- Modeling travel behavior
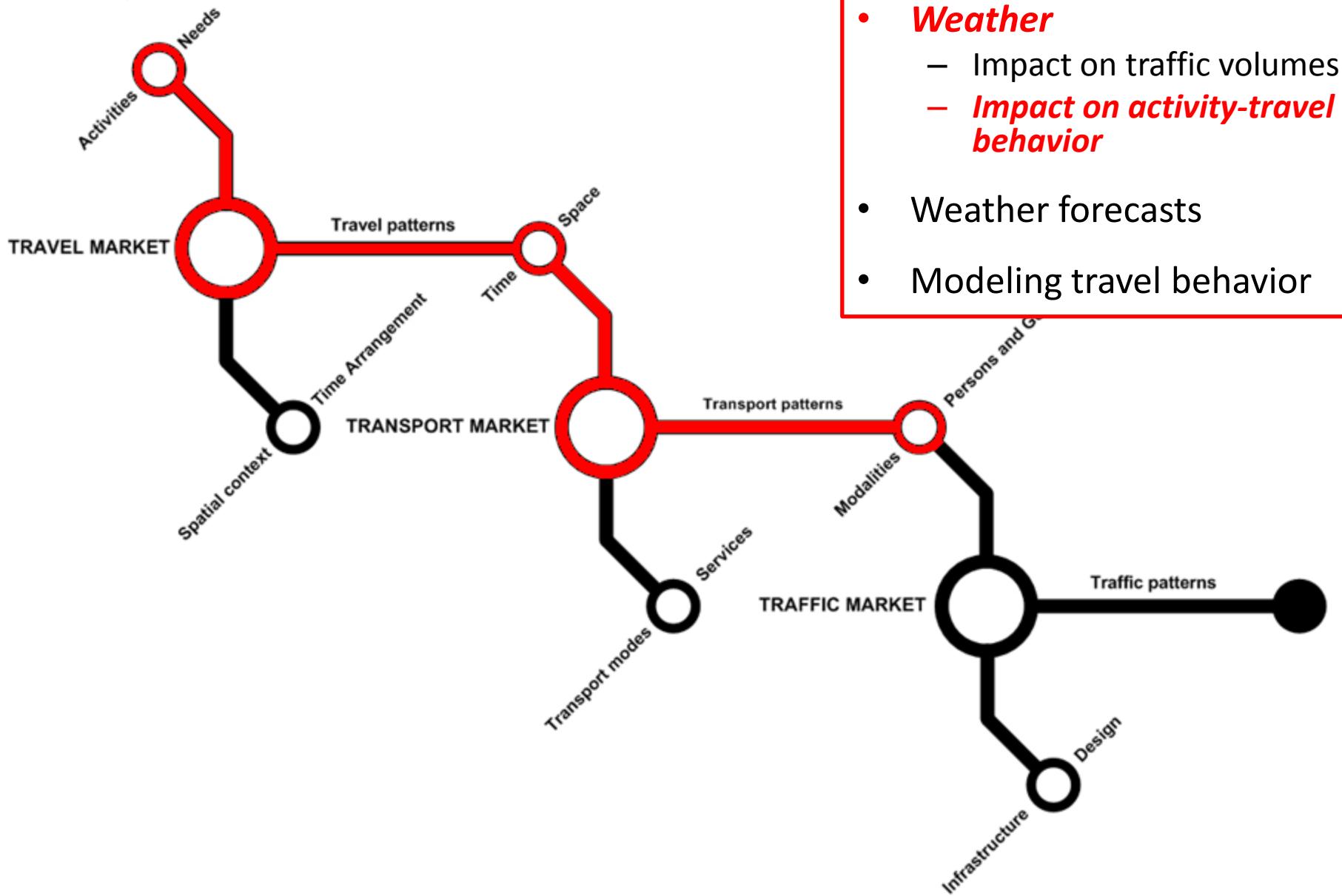
Effect of actual weather on changes in activity-travel behavior?

Data

- Stated-adaptation experiment
  - 586 respondents (86.7% internet, 13.3% P&P)
  - 6 weather conditions
  - 5 changes in activity-travel behavior
    - Change in transport mode
    - Change in timing of the trip
    - Change in activity location
    - Change in route of the trip
    - Cancellation of the trip
  - 3 trip purposes (commuting, shopping, leisure)
  - 2 series **("true" weather** and forecasted weather)

Experiment

Do you <u>postpone</u> or <u>advance</u> your work/school-related trip to a later/earlier moment the same day due to any of the following weather conditions?

*Mark the answer that corresponds mostly to your situation. Only **one** answer is possible for **each weather condition**.*

	No, never	Yes, occasionally (<25% of the cases)	Yes, sometimes (<50% of the cases)	Yes, usually (>50% of the cases)
Cold temperature	O	O	O	O
Snow/freezing rain	O	O	O	O
Heavy rain/thunderstorm	O	O	O	O
Fog	O	O	O	O
Warm temperature	O	O	O	O
Storm/heavy wind	O	O	O	O

Descriptives

T1: Frequencies of TB-changes to weather conditions (selection)							
Change	Freq.	Snow Commuting	Rain	Snow Shopping	Rain	Snow Leisure	Rain
Mode Change	Never	75.8%	84.8%	78.2%	85.6%	74.4%	83.9%
	1-25%	14.6%	7.9%	11.2%	6.0%	13.5%	8.9%
	26-50%	2.6%	1.4%	3.4%	2.2%	3.8%	3.1%
	>50%	7.0%	5.9%	7.2%	6.2%	8.3%	4.1%
TOD Change	Never	47.8%	70.3%	29.4%	41.8%	35.1%	54.3%
	1-25%	23.7%	17.0%	28.2%	24.1%	30.9%	26.1%
	26-50%	9.2%	6.9%	16.9%	13.6%	15.0%	12.7%
	>50%	19.3%	5.8%	25.5%	20.5%	19.0%	6.9%

- Pearson chi-square independence tests

$$Q_p = \sum_{i=1}^{k} \sum_{j=1}^{l} \frac{\left(n_{ij} - \hat{\mu}_{ij} \right)^2}{\hat{\mu}_{ij}}$$

- Cramer's V as an indicator of the degree of association

$$V = \sqrt{\frac{Q_p}{N(m-1)}}$$

Impact of weather type

T2: Dependence of change in travel behavior on type of weather					
Trip purpose	Behavioral change	Chi^2	DF	Signif.	Cramer's V
Commuting	Mode change	138.71	15	***	0.123
	TOD change	409.05	15	***	0.212
	Location change	81.12	15	***	0.094
	Trip cancellation	174.79	5	***	0.240
	Route change	362.56	15	***	0.199
Shopping	Mode change	92.24	15	***	0.095
	TOD change	542.97	15	***	0.230
	Location change	235.69	15	***	0.152
	Trip cancellation	555.65	15	***	0.233
	Route change	302.34	15	***	0.172

Conclusions

- Changes in activity-travel behavior dependent on
  - Type of weather
  - Trip purpose
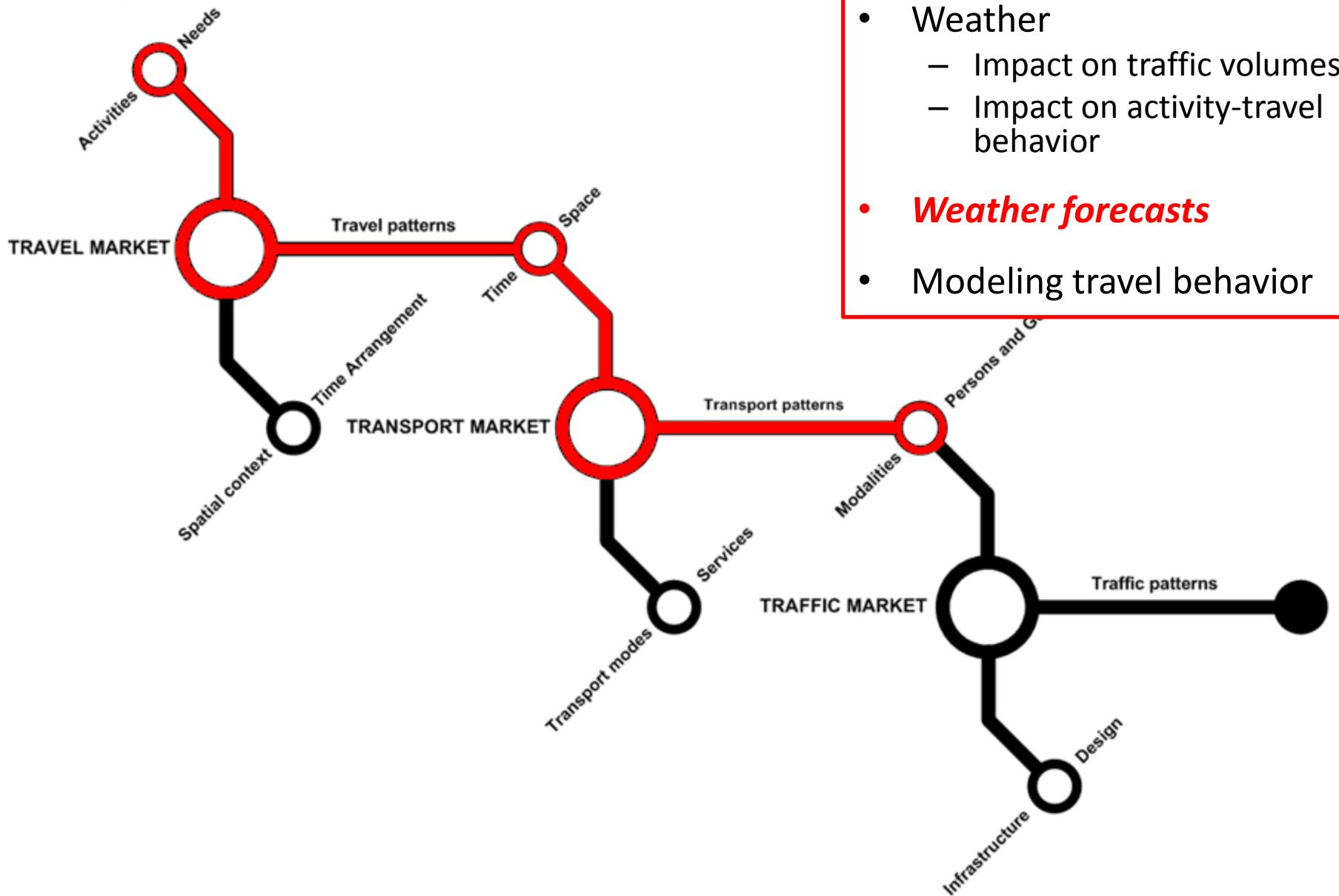
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- Weather
  - Impact on traffic volumes
  - Impact on activity-travel behavior

- *Weather forecasts*

- Modeling travel behavior

Weather forecasts

Effect of weather forecasts on changes in activity-travel behavior?
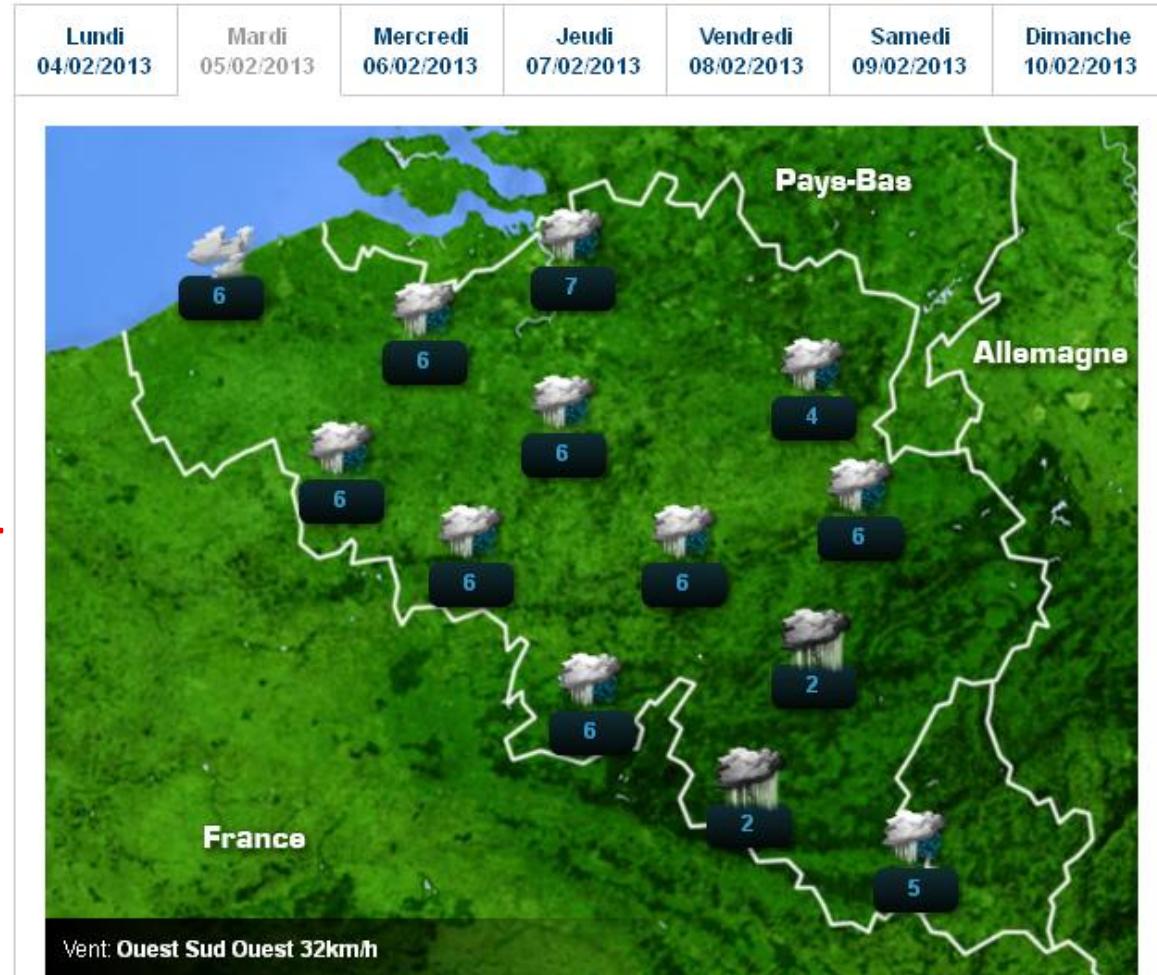
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- Methodology:
  - Independence tests
  - MNL-model

- Of particular interest:
  - Exposure to weather forecasts
  - Perceived reliability of weather forecasts
  - Media source

A. Changes in activity-travel behavior

B. Exposure to weather forecasts

C. Perceived reliability of weather forecasts

D. Media source

E. MNL-model

A. Changes in ATB

- E.g. postponement of shopping trips

Change frequency	Cold	Snow	Rain	Fog	Warm	Storm
Never	87.4%	51.7%	60.9%	71.8%	85.5%	64.0%
1-25%	9.5%	23.0%	19.9%	15.4%	8.9%	18.8%
26-50%	1.5%	11.0%	9.5%	6.9%	3.4%	8.9%
>50%	1.6%	14.3%	9.8%	5.8%	2.3%	8.2%

- E.g. cancellation of leisure trips

Change frequency	Cold	Snow	Rain	Fog	Warm	Storm
Never	85.3%	51.3%	67.3%	76.0%	87.2%	66.3%
1-25%	9.8%	28.0%	19.0%	14.4%	9.4%	20.5%
26-50%	2.8%	10.7%	8.1%	5.1%	2.1%	7.8%
>50%	2.0%	10.0%	5.5%	4.6%	1.3%	5.4%

- Dependence of changes in ATB on
    - Type of weather:
        - All highly significant (p <0.001)

    - Activity type:
        - Cancellation of trips, and activity location highly dependent on activity type across all weather types
        - Modal changes, trip postponements: dependence differs according to weather type
        - Route changes NOT dependent on activity type

B. Exposure

- ## Exposure to weather forecasts

Exposure	Percentage
Daily	59.3%
Weekly	33.2%
Occasional	7.5%

- ## Exposure to weather forecasts

  - Non-significant effect on changes in ATB:
    the degree of exposure to weather forecasts has
    no influence on ATB

C. Perceived reliability

- ## Perceived reliability of weather forecasts

Statistic	Value/percentage
Mean	6.89
Median	7.00
Score 0-5	15.4%
Score 6-10	84.6%

- ## Effect on changes in ATB

  - Perceived reliability has an effect: persons which have a low perceived reliability (0-5) are LESS inclined to make changes

D. Media source

- ## Media source of weather forecasts

Media source	Percentage
Television	81.2%
Radio	63.4%
Internet	23.1%
Newspaper	22.9%

- ## Effect on changes in ATB
  - Radio triggers a higher number of changes
  - But, in general NO effect of the media source

E. MNL model

- ## Hierarchy (prioritization) in ATB changes

Change FREQ	Mode	TOD	Location	Deletion	Route
Never	16				
1-25%	9	15	7	6	14
26-50%	8	13	4	3	12
>50%	5	11	2	1	10

- ## Explanatory variables

  - Socio-demographics

  - Activity and trip related attributes

  - Weather forecast attributes
    (weather condition, forecast media, perceived reliability, …)

E. MNL model

- ## Influencing factors (type III p-values)

Variables	Work (1)	Work&School (2)	Shopping (3)	Leisure (4)
Weather condition	<0.001	<0.001	<0.001	<0.001
Age	-------	<0.001	-------	<0.001
Gender	-------	-------	0.003	-------
Children	0.056	0.031	-------	-------
Degree	-------	-------	-------	0.025
Flexible work hours	0.011	n.a.	n.a.	n.a.
Profession /statute	-------	-------	0.022	-------
Driving license	-------	-------	0.015	0.023
PT season ticket	-------	0.005	-------	-------
Urbanization	-------	<0.001	-------	-------

Discussion

- ## Implications for travel demand forecasting

- ## Validity stated adaptation experiment
  (ATB dependence on weather illustration for shopping trips)

ATB Changes	Chi² FW	DF FW		Chi² AW	DF AW
All	903.1	95		1728.9	95
Mode	57.6	15		92.2	15
TOD	290.5	15		543.0	15
Location	101.0	15		235.7	15
Deletion	291.5	15		555.7	15
Route	162.5	15		302.3	15

Conclusions

- Dual role of weather information
  - Weather forecasts trigger changes in ATB
  - Frequency and media source have no/only limited impact

- Further research
  - Revealed activity-travel behavior
  - Integration with travel demand models

- Introduction

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- *Modeling travel behavior*
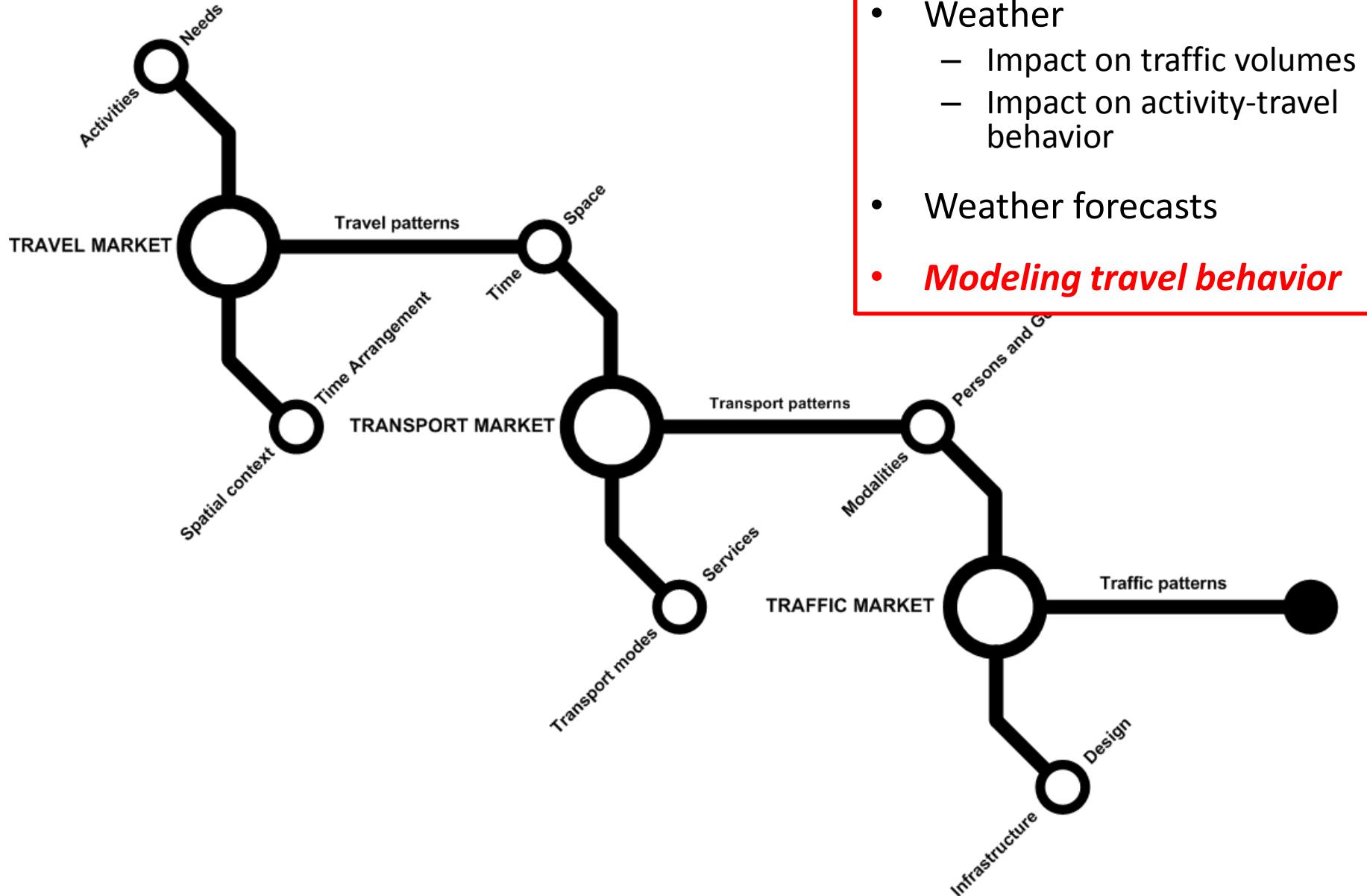
WEATHER MATTERS!

Questions and answers?

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