避難目的地と開始時刻同時モデル

A joint estimation model of destination choice and evacuation timing

Giancarlos Troncoso Parady
Research Associate, Urban Redesign Studies Unit

International BinN Seminar #3

発表の流れ

Presentation outline

PART I: Theoretical Aspects

Research scope and previous studies
研究範囲と既往研究

Disaggregate modeling approaches in previous studies
既往研究による非集計モデリングアプローチ

Knowledge gap
知識格差

Evacuation timing model description
避難開始時間モデル記述

Destination choice model description
目的地選択モデル記述

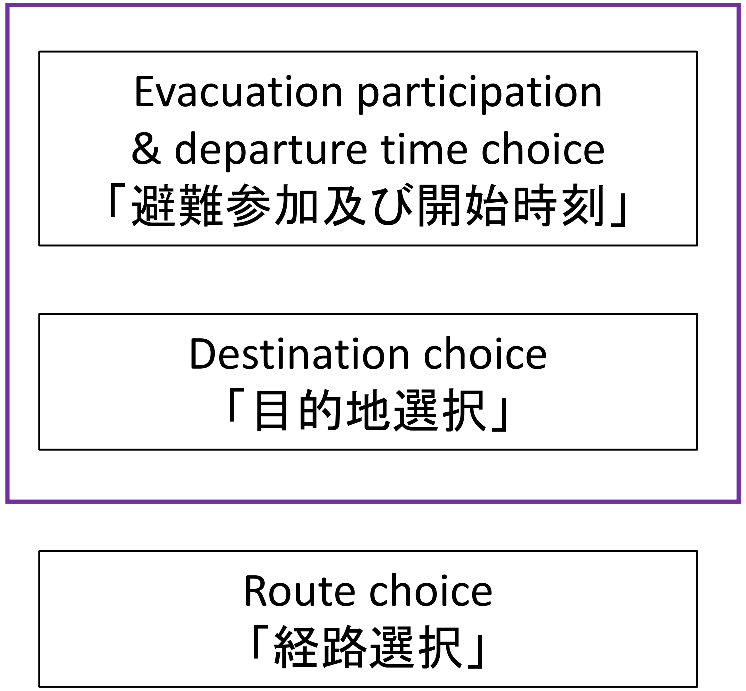
Regarding the joint model estimation
同時推定について

PART II: Case study of Kesennuma City

研究範囲と既往研究

Research scope and previous studies

Evacuation behavior modeling framework
避難行動モデル枠組み



Evacuation participation & departure time choice
「避難参加及び開始時刻」

Destination choice
「目的地選択」

Route choice
「経路選択」

Evacuation timing modeling approaches
既往研究による避難開始時間モデリングアプローチ

① Aggregate models 集計モデル → Cumulative ratio models 累積比率モデル

② Disaggregate models 非集計モデル → Survival models 生存時間モデル / Discrete choice models 離散選択モデル

Destination choice modeling approaches
既往研究による目的選択肢モデリングアプローチ

① Aggregate models 集計モデル → Gravity models 重力モデル

② Disaggregate models 非集計モデル → Discrete choice models 離散選択モデル

既往研究による非集計モデリングアプローチ

Disaggregate modeling approaches in previous literature

Evacuation timing models
避難開始時間モデル

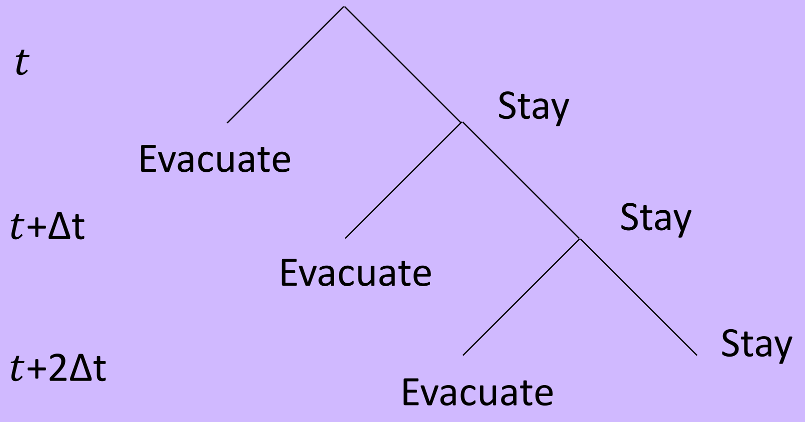
Sequential binary logit
逐次二項ロジットモデル

Survival model
生存時間モデル

$$P(t)_{s/c}\prod_{j=1}^{t-1}\left[1-P(j)_{s/c}\right]$$

(Fu and Wilmot (2004))

$P(t)_{s/c}$= Probability of evacuation at time interval t



Adapted from Pel et al. (2012)

既往研究による非集計モデリングアプローチ

Disaggregate modeling approaches in previous literature

Evacuation timing models

避難開始時間モデル

Sequential binary logit

逐次二項ロジットモデル

Survival models

生存時間モデル

Parametric hazard function (Urata and Hato (2013))

パラメトリックハザード関数：

$$\lambda_h(t|\boldsymbol{X_h}) = \lambda_0(t)e^{\boldsymbol{\beta}'\boldsymbol{X_h}}$$

Random parameter hazard function (Hasan et al. (2013))

ランダムパラメターハザード関数：

$$\lambda_h(t|\boldsymbol{X_h}, \boldsymbol{\omega_h}) = \lambda_0(t)e^{\boldsymbol{\beta}'_{\boldsymbol{h}}\boldsymbol{X_h}}$$

$$\beta_h = \beta + \omega_h$$

Weibull distributed base rate

ウェイブル分布したハザード基準率

$$\lambda_o(t) = \lambda P(\lambda t)^{p-1}$$

$\boldsymbol{X_h}$： Covariates affecting the hazard rate

$\boldsymbol{\omega_h}$： Random parameter

（パラメトリック手法）　（Parametric Approach）

既往研究による非集計モデリングアプローチ

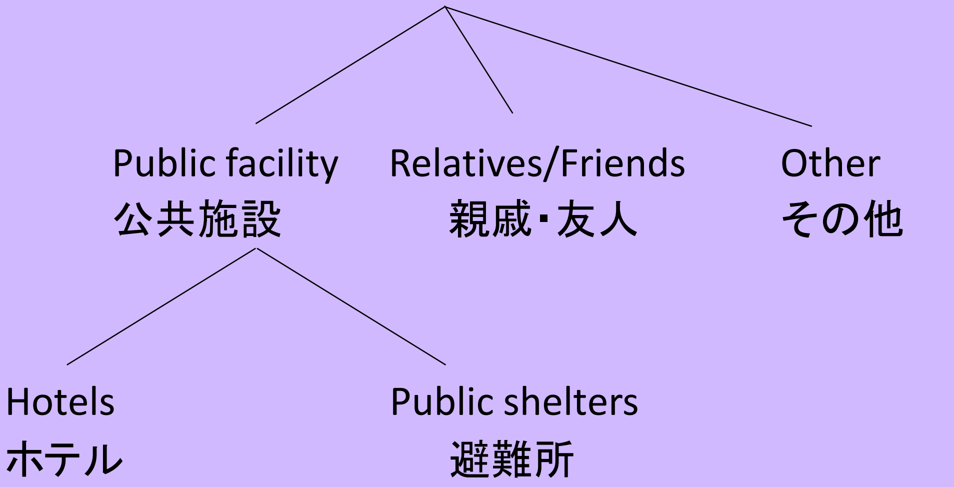
Disaggregate modeling approaches in previous literature

Destination choice models
目的地選択モデル

ロジットモデル
MNL・NL models

Destination choice models
（separated by destination type)
(Cheng, Wilmot and Baker (2008))
類型別目的地選択モデル

Nested logit model of destination type
(Mesa-arango et al. (2013))
目的地タイプネステッドロジット



知識格差

Knowledge gap

既往研究による、避難以外の活動はほとんど考慮せずこと

In disaster situations, trips other than evacuation are rarely considered

避難開始、目的地選択などの行動モデルは別々に推定すること

In most studies, activities such as evacuation timing, destination choice, etc. are modelled independently.

避難開始時間モデル記述

Evacuation timing model description

Accelerated failure time model (AFT)

パラメトリック生存時間モデル：加速モデル

Survival function $[P(T \geq t)]$
生存関数

(The explanatory variables rescale time directly)

$$\mathrm{S}(t, \boldsymbol{X}, \theta) = \mathrm{S}_0\left(t e^{\theta \boldsymbol{X}}\right)$$

Hazard function $\left[\frac{f(t)}{\mathrm{S}(t,\boldsymbol{X},\theta)}\right]$
ハザード関数

$$\lambda(t, \boldsymbol{X}, \theta) = \lambda_0\left(t e^{\theta \boldsymbol{X}}\right) e^{\theta \boldsymbol{X}}$$

t=observed evacuation time
観測した避難開始時刻

X=a vector of covariates
共変数のベクトル

θ =a vector of parameters to be estimated
推定するパラメータのベクトル

Model linear specification*
モデルの線形指定

$$Y = \mu + \sigma u$$

$$Y = \ln(t) \qquad \mu = \theta \boldsymbol{X} \qquad u = \frac{Y - \mu}{\sigma}$$

σ =Scale parameter

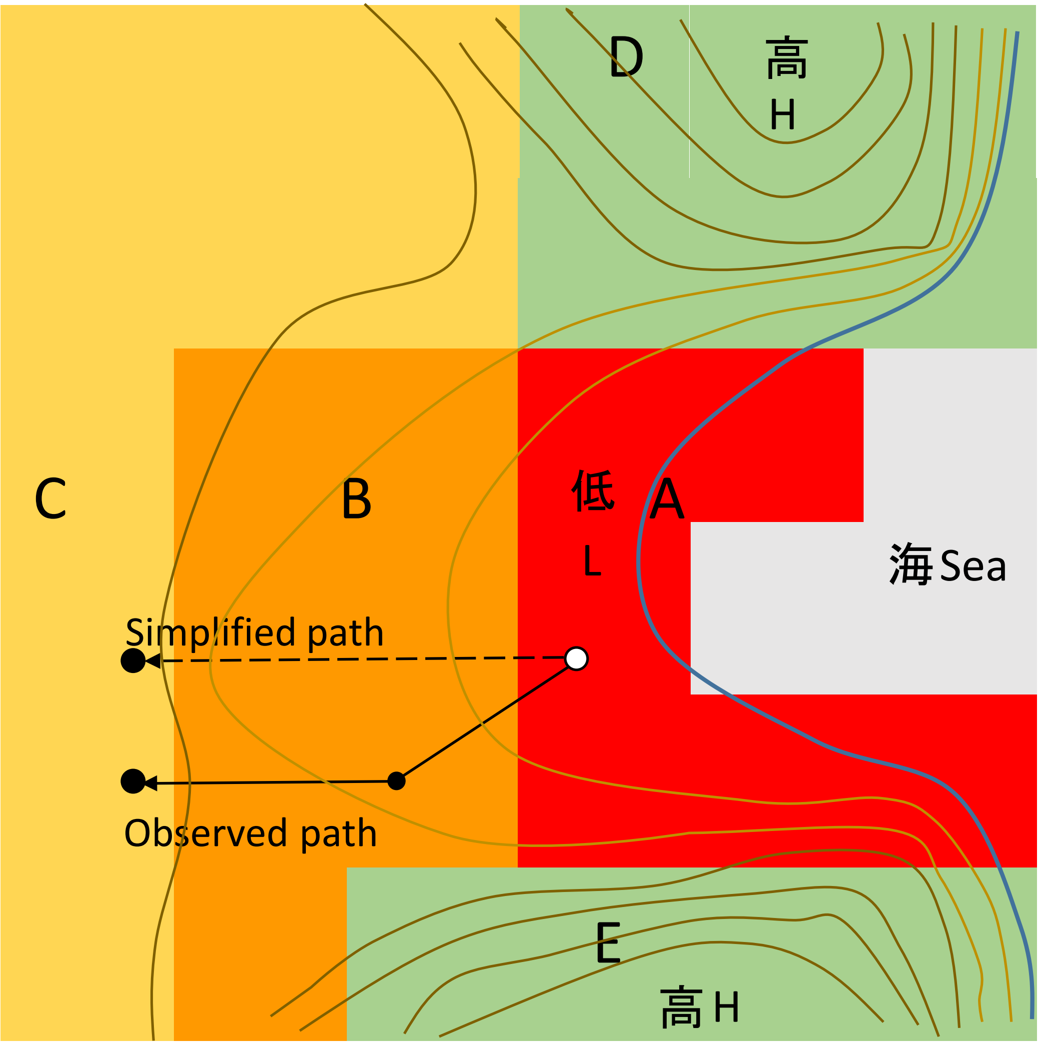
Normally distributed error → Lognormally distributed time t
正規分布した誤差項 → 対数正規分布したt

*A linear regression model where σ is estimated as an ancillary parameter

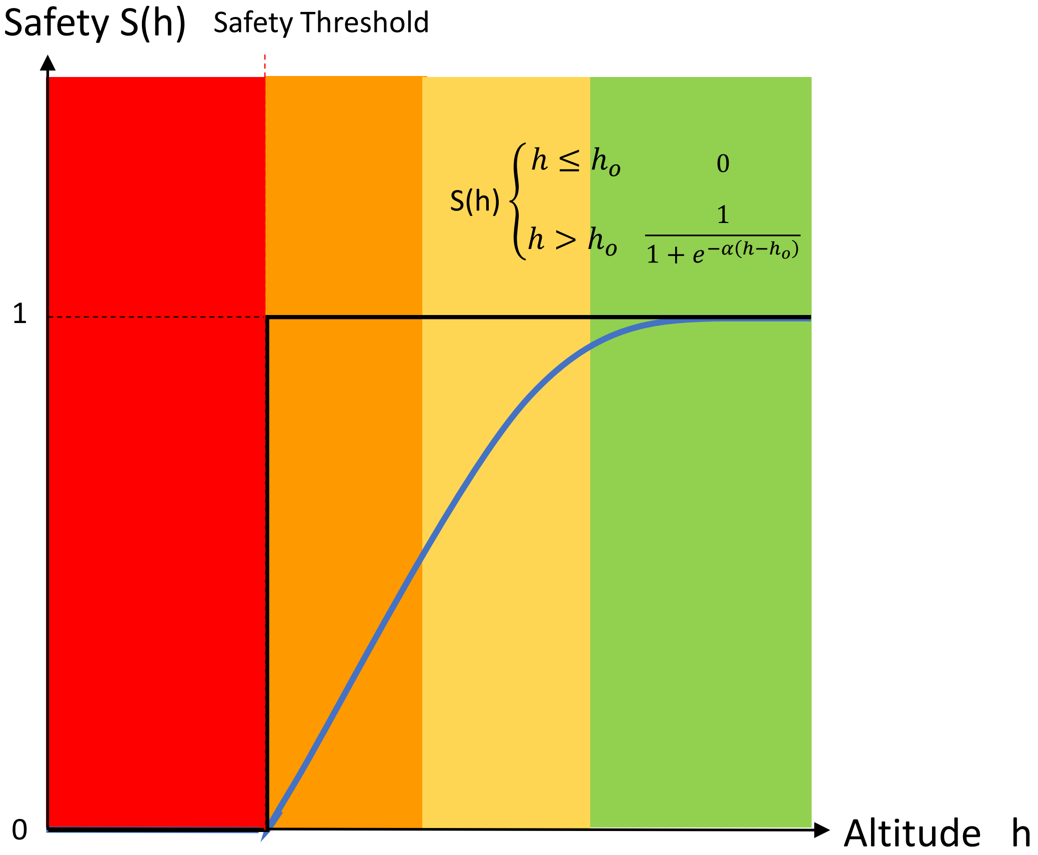
目的選択モデル記述

Destination choice model description

A simplification of the model
目的地選択単純化



- Alternatives aggregated based on altitude 標高で選択肢集合
- Only final evacuation considered 最終目的のみ（ツアーを考慮せず）
- **Multinomial Logit**, Spatially Correlated Logit, Generalized Nested Logit



$$S(h)\begin{cases} h \le h_o & 0 \\ h > h_o & \dfrac{1}{1+e^{-\alpha(h-h_o)}} \end{cases}$$

同時推定における
Regarding the joint model estimation

The premise: The error terms of both models are correlated. However,

前提：各モデルの誤差項が相関している。しかし、

MNL error terms ε_d →Gumbel distributed

MNLの誤差項ε_d→ガンベル分布

$$F(\varepsilon_d) = \frac{\exp(V_{di})}{\exp(V_{di}) + \sum_{e\neq d}^{N} \exp(V_{ei})}$$

AFT error terms α_t → Normally distributed

生存の誤差項α_t→正規分布

$$\mathrm{F}(\alpha_t) = \Phi\left(\frac{Y-\mu}{\sigma}\right) = \Phi\left(\frac{\ln(t_d) - \theta X_d}{\sigma_{dt}}\right)$$

Φ=Normal CDF. 正規分布の累積分布関数

d＝destination. 目的地

To specify the correlation between both error terms, both distributions are converted to a normalized standard distribution.

正規分布と非正規分布変数の相関を指定するため、標準正規分布の接合分布を指定する。

$$\varepsilon^* = J_1(\varepsilon_d) = \Phi^{-1}\mathrm{F}(\varepsilon_d)$$

$$\alpha^* = J_2(\alpha_t) = \Phi^{-1}\mathrm{F}(\alpha_t)$$

Φ^{-1}=Inverse of the CDF. 逆累積分布関数

Reference:(Lee(1983), Habib et al (2009))

同時推定における

Regarding the joint model estimation

$$P(time = t_d | destination = d) = P(time = t_d | \varepsilon \leq J_1(\varepsilon_d) = \frac{1}{t_d \sigma_{dt}} \varphi\left(\frac{\ln(t_d) - \theta X_m}{\sigma_{dt}}\right) \Phi\left(\frac{J_1(\varepsilon_d) - \rho_{dt} \cdot J_2(\alpha_{dt})}{\sqrt{1 - \rho_{dt}^2}}\right)$$

ρ=error term correlation parameter . 誤差項相関パラメーター

σ=variance of the AFT model

The likelihood function to maximize is then,

最大化する尤度関数は、

$$\mathrm{L} = \prod_{i=1}^{N} \prod_{d=1}^{D} \left(\frac{1}{t_d \sigma_{dt}}\right)^{D_{di}} \left(\varphi\left(\frac{\ln(t_d) - \theta X_m}{\sigma_{dt}}\right) \Phi\left(\frac{J_1(\varepsilon_d) - \rho_{dt} \cdot J_2(\alpha_{dt})}{\sqrt{1 - \rho_{dt}^2}}\right)\right)^{D_{di}}$$

D_{di} = Dummy variable indication selected choice

$$\mathrm{LL} = \mathrm{L} \sum_{i=1}^{N} \sum_{d=1}^{D} D_{di} \left\{ ln\left(\varphi\left(\frac{\ln(t_d) - \theta X_m}{\sigma_{dt}}\right)\right) - \ln(t_d \sigma_{dt}) + ln\left(\Phi\left(\frac{J_1(\varepsilon_d) - \rho_{dt} \cdot J_2(\alpha_{dt})}{\sqrt{1 - \rho_{dt}^2}}\right)\right)\right\}$$

Reference:(Lee(1983), Habib et al (2009))

PART II: Destination Choice Case Study

A joint estimation model of destination choice and evacuation timing

Behavior in Networks Studies Unit

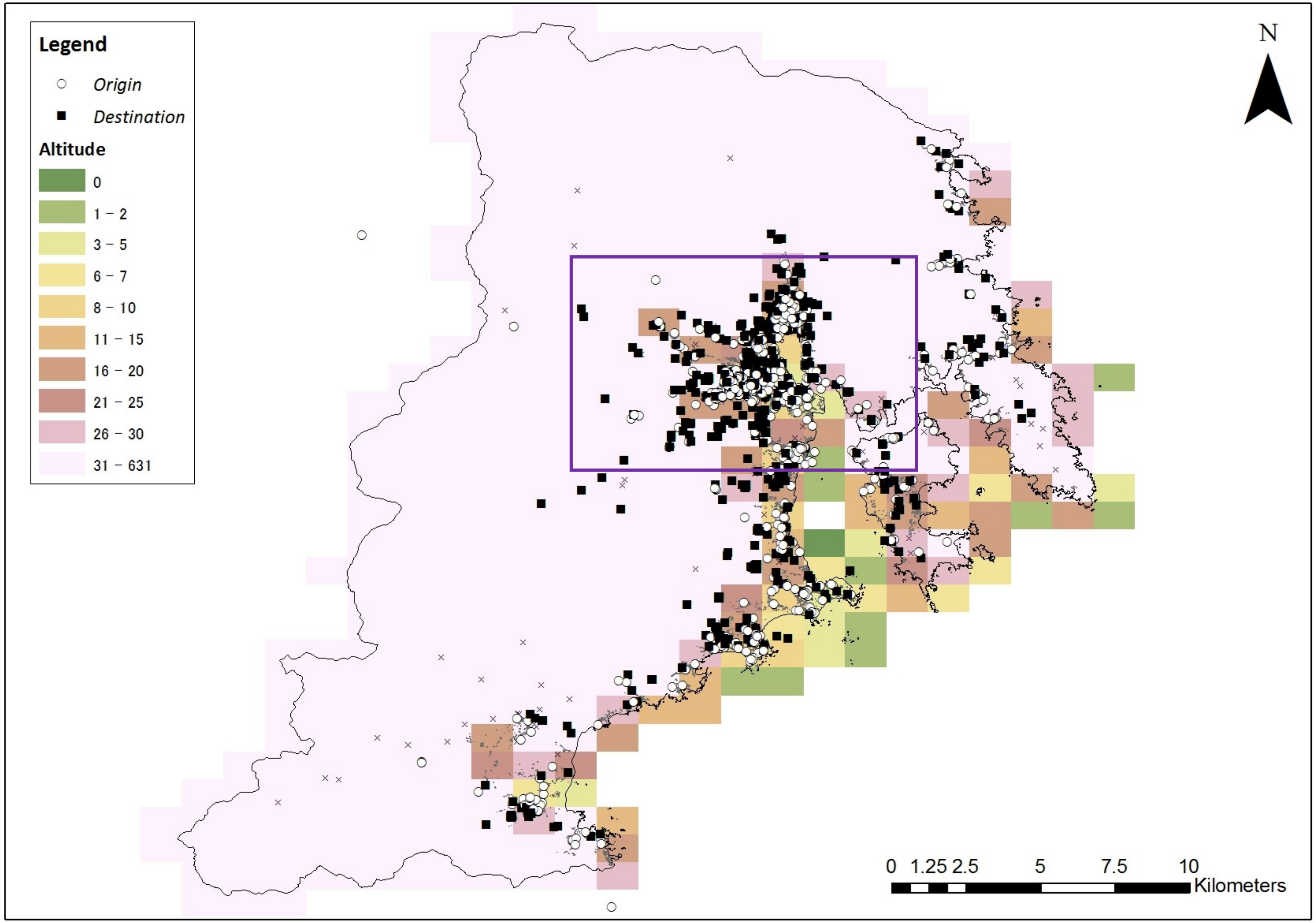
目的地選択モデル:気仙沼を例として

避難目的地と開始時刻同時モデル

PART II: Case study of Kesennuma City

A joint estimation model of destination choice and evacuation timing

bin Behavior in Networks Studies Unit



Source: npr.org

General characteristics:

- Population(As of Dec. 2014): 67,657
- 3.11. situation:
  - 690 Death 死亡
  - 1,531 Missing 行方不明
  - 8,884 Evacuees 避難者
- Maximum Flood height:
  最大浸水深さ
  - *19.40m*
- Reported Tsunami height:
  (During evacuation advisory)
  予想された津波高さ
  - 6m (Most frequent answer)

目的地選択モデル：気仙沼を例として

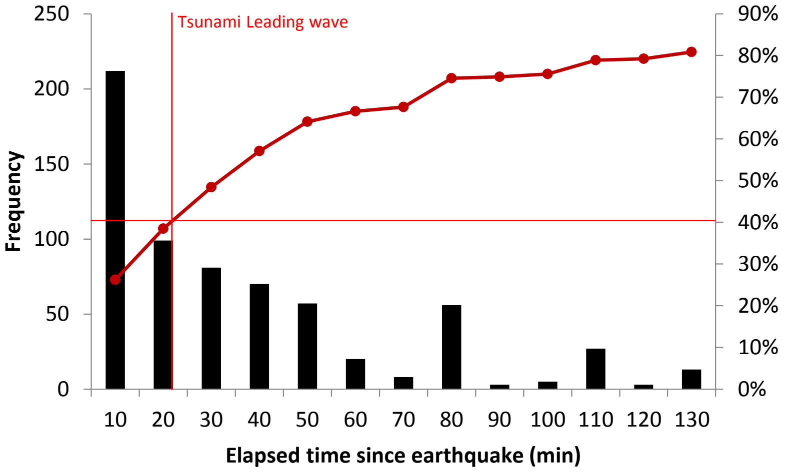
避難目的地と開始時刻同時モデル

PART II: Case study of Kesennuma City

A joint estimation model of destination choice and evacuation timing

Images source: http://www.jptopic.org

Distribution of evacuation times



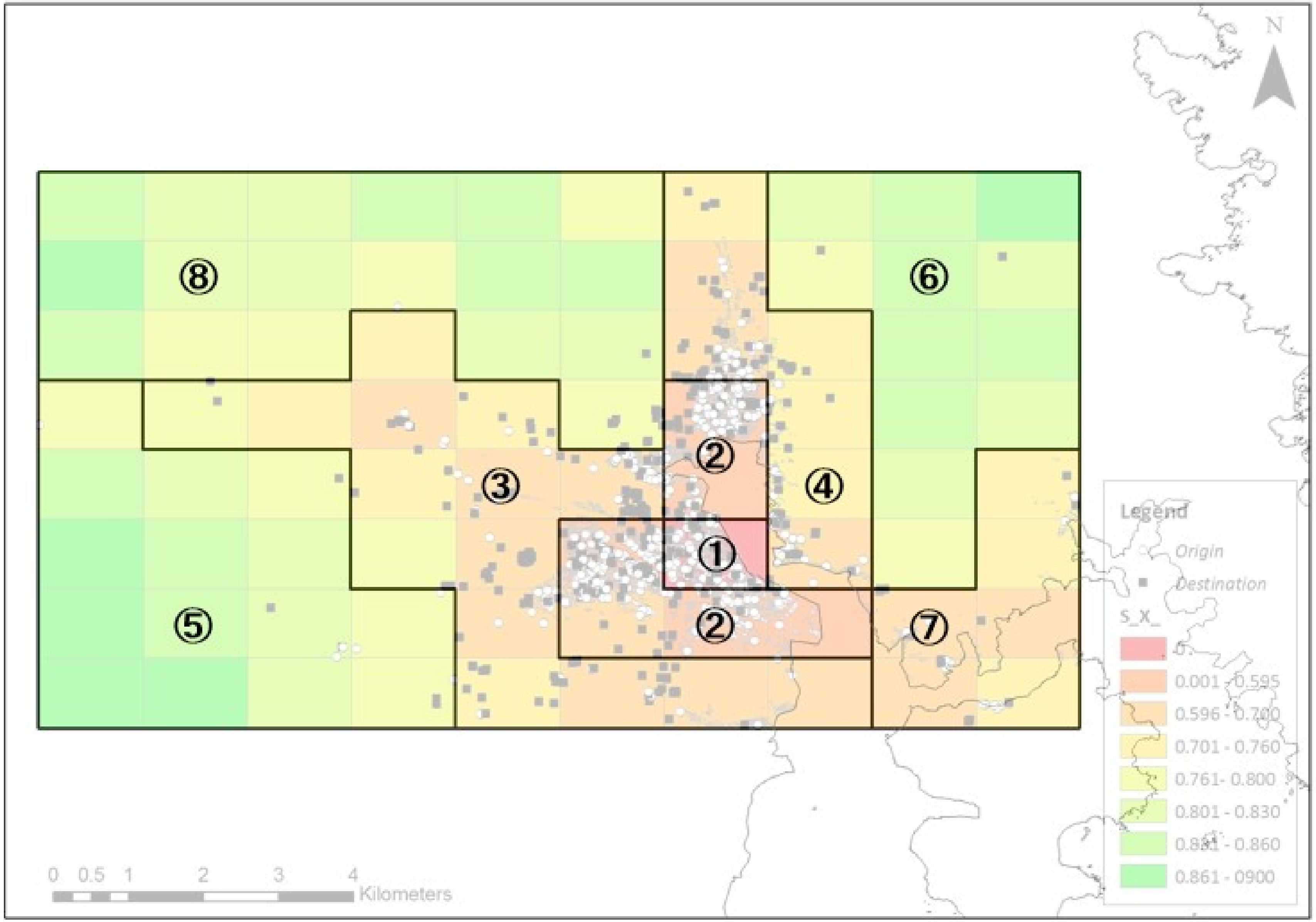
Source: npr.org

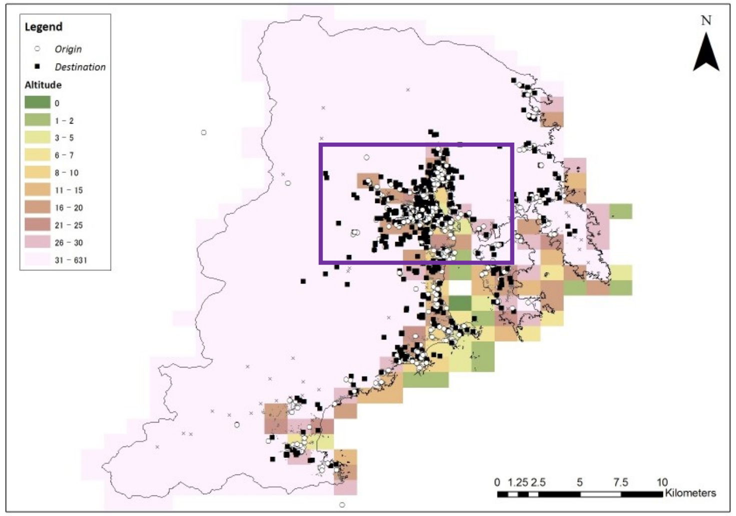
General characteristics:

- Population(As of Dec. 2014): 67,657
- 3.11. situation:
  - 690 Death 死亡
  - 1,531 Missing 行方不明
  - 8,884 Evacuees 避難者
- Maximum Flood height:
  最大浸水深さ
  - *19.40m*
- Reported Tsunami height:
  (During evacuation advisory)
  予想された津波高さ
  - 6m (Most frequent answer)

目的地選択モデル：気仙沼を例として

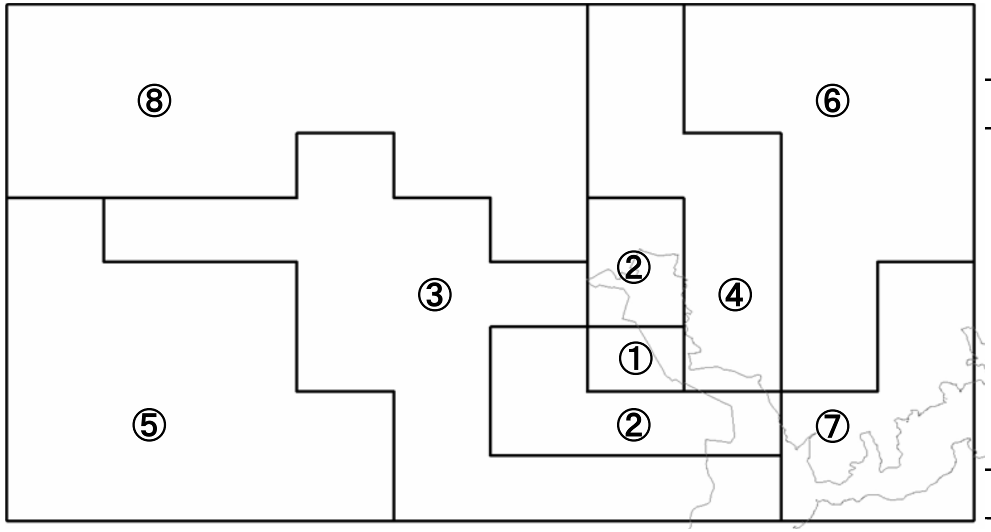
PART II: Case study of Kesennuma City





目的地選択モデル：気仙沼を例として

PART II: Case study of Kesennuma City



OD matrix of evacuation trips (Final evacuation site only)

O-D	1	2	3	4	5	6	7	8	Total
1	30	21	23	0	0	0	0	0	**74**
2	8	121	107	31	2	1	0	8	**278**
3	1	12	29	6	1	1	1	6	**57**
4	0	1	2	43	0	0	5	3	**54**
5	0	1	2	1	0	0	0	0	**4**
7	0	0	0	0	0	0	13	0	**13**
8	0	1	0	0	0	0	0	0	**1**
Total	**39**	**157**	**163**	**81**	**3**	**2**	**19**	**17**	**481**

General zonal characteristics

Zone	Average altitude(m)	Average slope (angle)	Number of buildings (Size variable)	Number of safe buildings (Over 3F, RC or SS)	Average Flooding (m)	Maximum Flooding (m)
ゾーン	平均標高	平均傾斜角度	建物数（サイズ変数）	安全な建物数（３階以上鉄筋コン等）	平均浸水深さ	最大浸水深さ
1	3.20	0.30	6,444	95	4.34	11.2
2	9.38	1.73	9,685	107	3.02	14.6
3	37.21	3.21	8,355	101	1.43	14.6
4	38.81	4.73	6,474	55	1.94	14.6
5	175.72	7.29	151	1	0.02	1.1
6	144.90	7.76	2,064	8	1.88	14.6
7	44.08	4.67	1,193	2	4.51	14.6
8	134.88	7.70	3,780	51	0.39	8.5

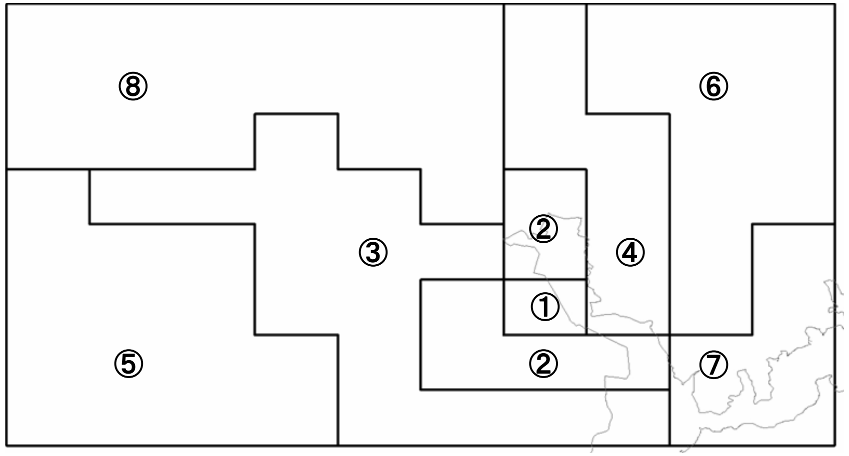
目的地選択モデル:気仙沼を例として

避難目的地と開始時刻同時モデル

PART II: Case study of Kesennuma City

A joint estimation model of destination choice and evacuation timing

Parameter name	Coefficient	S.E.	t-stat
Destination choice parameters			
Log of OD distance*Car	-0.083	0.020	-4.139
Log of OD distance*Other	-0.255	0.022	-11.517
Log of OD altitude difference(m)	1.608	0.163	9.839
Log of OD altitude difference^2	-0.205	0.042	-4.909
Average slope	-0.596	0.089	-6.706
Size variable (Log of number of buildings)	0.829	0.121	6.869
Evacuation time parameters			
Constant	2.545	0.336	7.571
Evacuation mode car	0.592	0.142	4.157
Log of altitude at origin	0.307	0.090	3.405
Knows refuge locations	-0.422	0.173	-2.433
Elder	-0.246	0.138	-1.777



Parameter name	Coefficient	S.E.	t-stat
Accelerated failure time model variances			
σ_1	1.093	0.131	8.375
σ_2	1.453	0.083	17.556
σ_3	1.602	0.090	17.746
σ_4	1.512	0.121	12.499
σ_5	1.545	0.531	2.908
σ_6	0.861	0.404	2.130
σ_7	1.204	0.197	6.110
σ_8	1.318	0.229	5.763
Correlation coefficients			
ρ_1	0.157	0.158	0.993
ρ_2	0.059	0.138	0.428
ρ_3	-0.266	0.122	-2.179
ρ_4	-0.083	0.120	-0.694
ρ_5	0.464	0.213	2.175
ρ_6	0.374	0.320	1.170
ρ_7	0.097	0.166	0.587
ρ_8	0.061	0.136	0.448

LL(0)	-5975.84
LL(β)	-3006.84
ρ^2	0.497
adjusted ρ^2	0.496

Conclusions and limitations

The direction of the effects of parameters behaves as hypothesized in all models

Some correlations were observed between destination choice and departure time, which validates to some extend this approach, but requires further analysis

Results might be sensitive to the aggregation scheme used, both in terms of zoning and scale (MAUP problem)

A more rigorous approach to alternative aggregation is needed

Not considered in this analysis:

- Network conditions
- Tour behavior
- Multiple evacuations