Modeling Household Social-Recreational Activity Participation Patterns: Emphasis on Inter-personal Interactions

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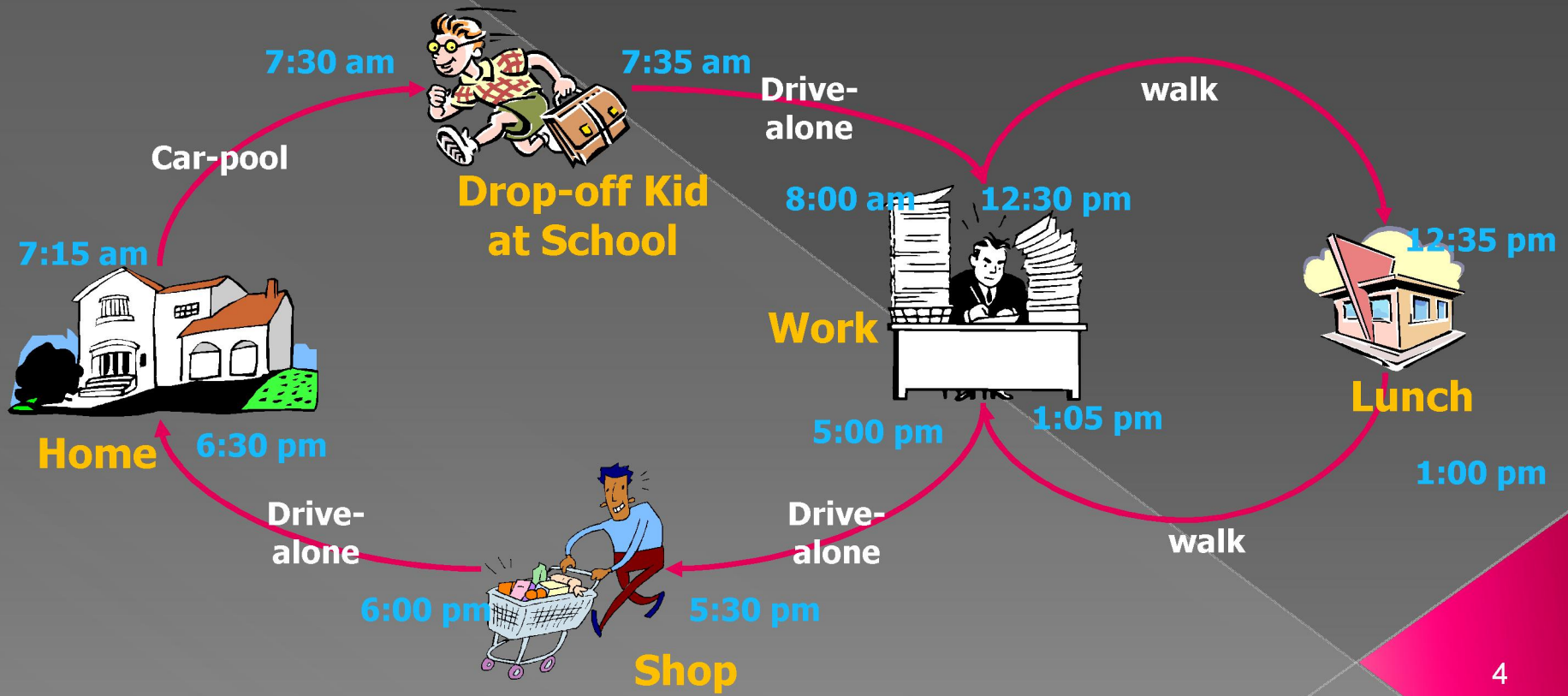
Agenda

- Quick Overview of Trip- and Activity-based Method
- Modeling Household Inter-personal Interaction
  - Is the Inter-personal Interaction a matter within a Travel Demand Framework
  - Data Compromising
  - Model Specification
  - Analysis Results
  - Predictive Validations and Sensitivity Tests
  - Conclusions

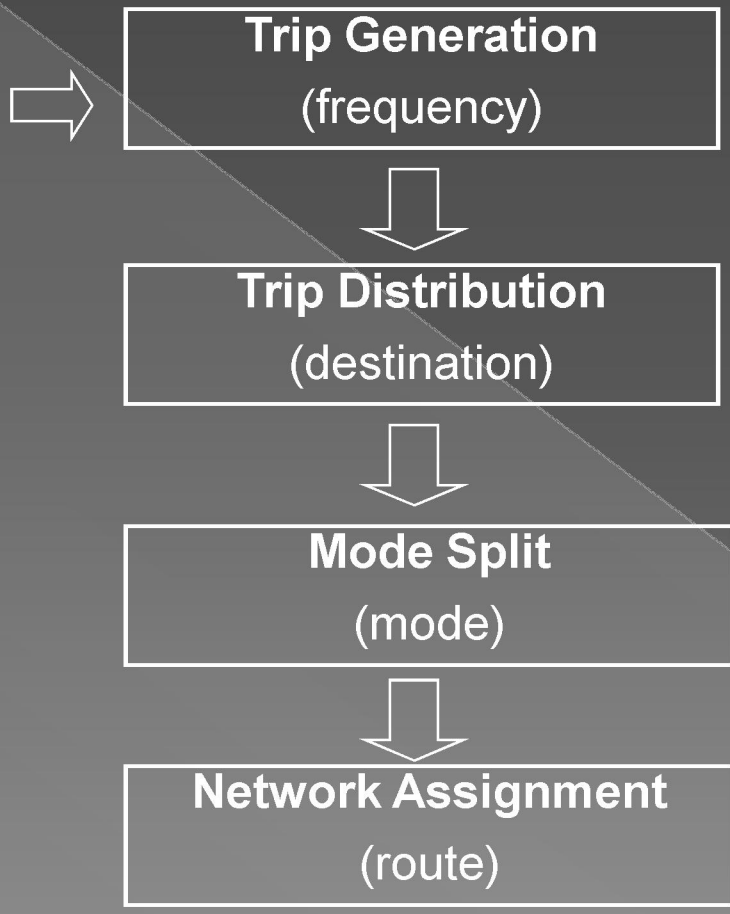
Overview of Trip- and Activity-based Method

A Travel Pattern of a Person in a Day



Analytical Methodology: The State-of-Practice Approach, "Four-Step" Model System

- Socio-economic characteristics
- Land-use patterns
- Transportation system characteristics



Link flows, speeds, travel times, transit-ridership, etc.

Critique of the Trip-based Approach: Measurement & Modeling

The trip-based method views this person's travel as:

One Home-based Other trip

H → A1 : Drive, Peak

One Home-based Shop trip

H → A2 : Drive, Peak

Four Non home-based trips

P3 → A3 : Drive, Peak

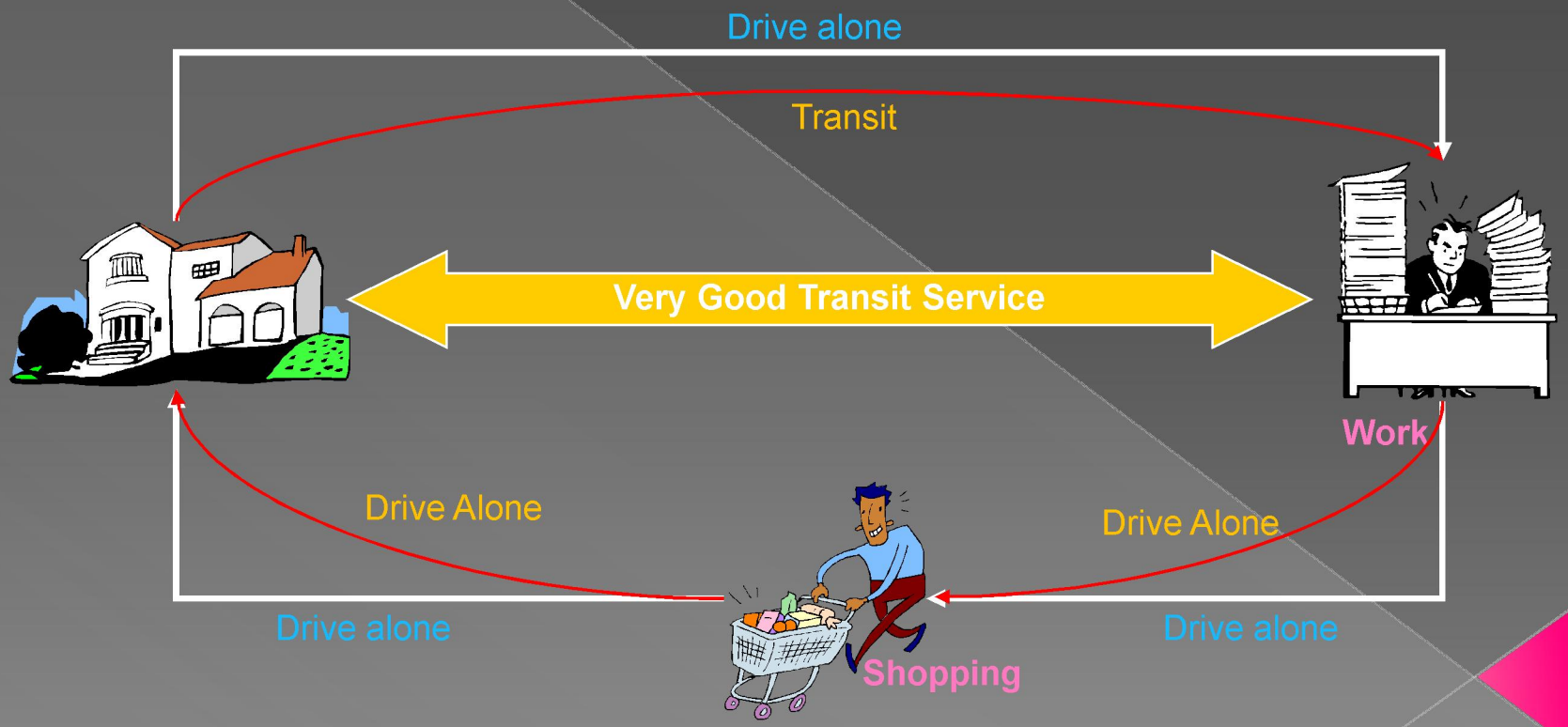
P4 → A4 : Drive, Peak

P5 → A5 : Walk, Off Peak

P6 → A6 : Walk, Off Peak

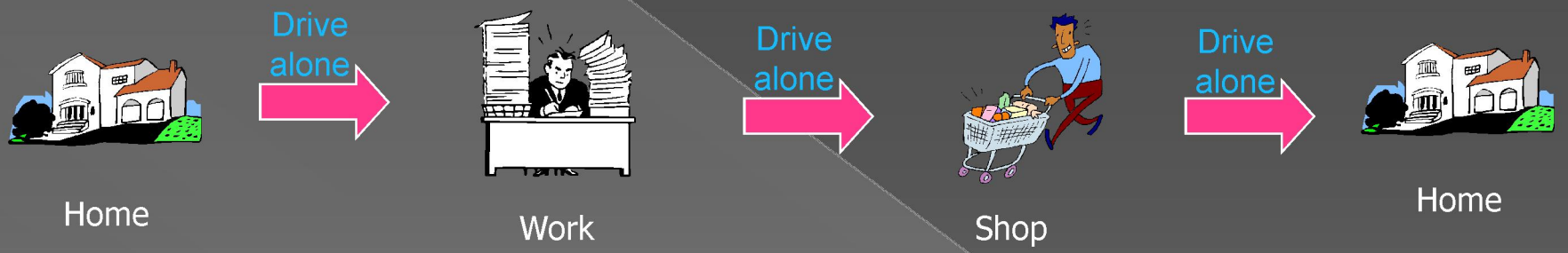
Critique of the Trip-based Approach: Measurement & Modeling

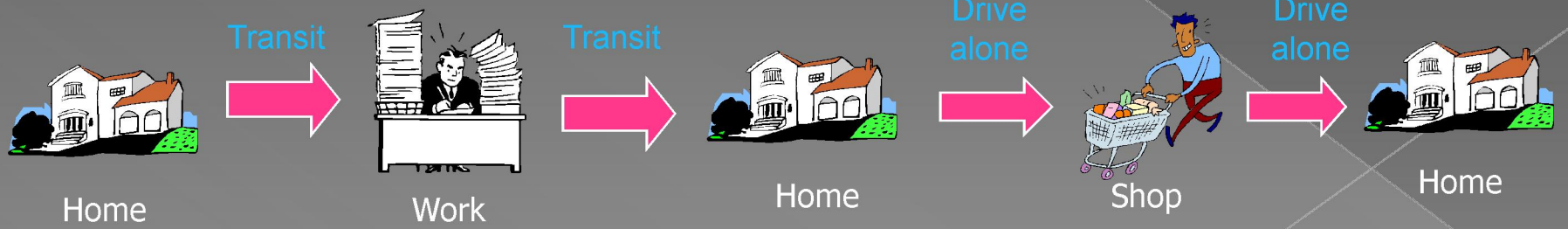
Example 1: Effect of Transit Improvements



Critique of the Trip-based Approach: Measurement & Modeling

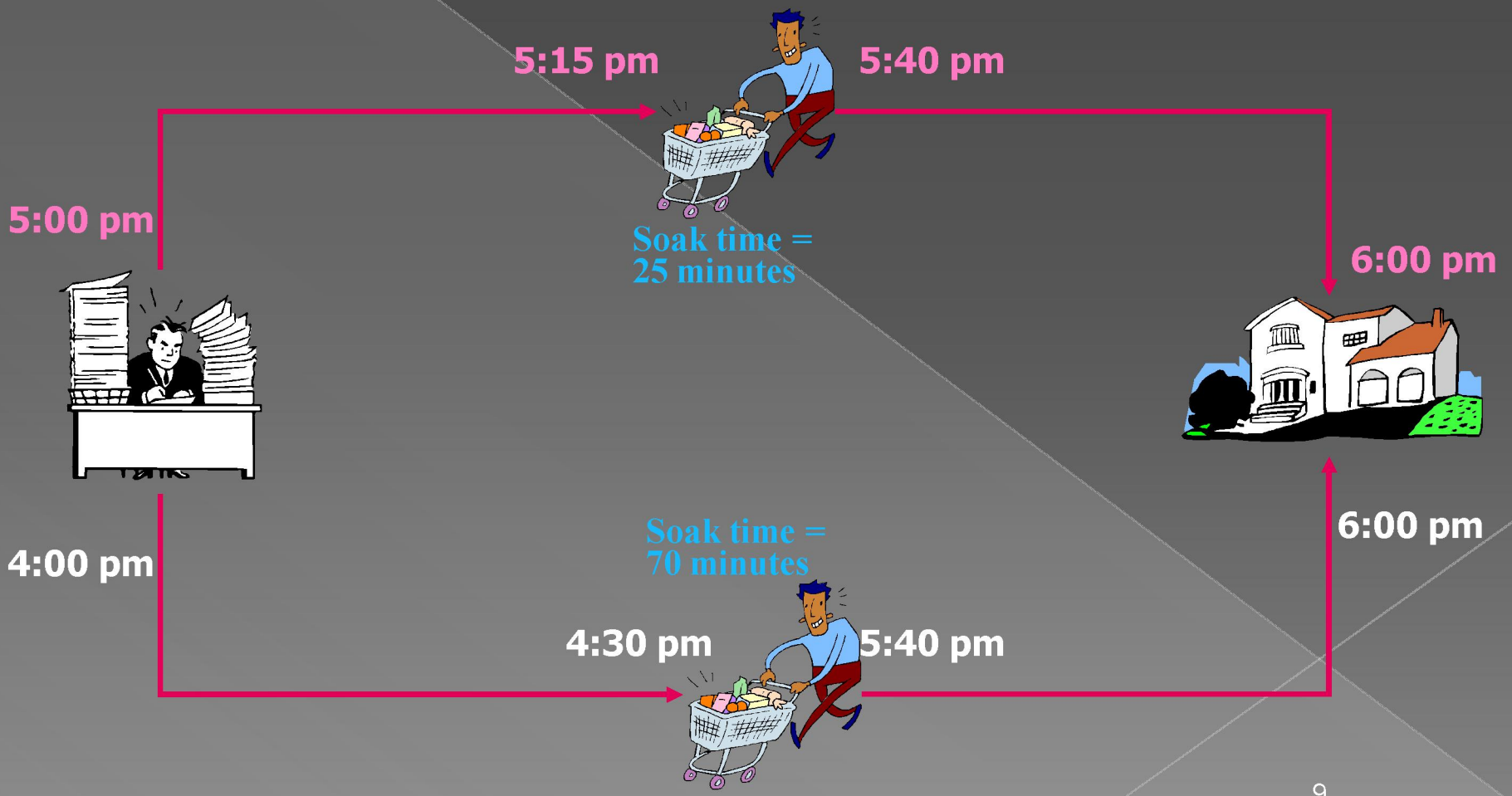
Example 2: Effect of Transit Improvements (alternate responses)





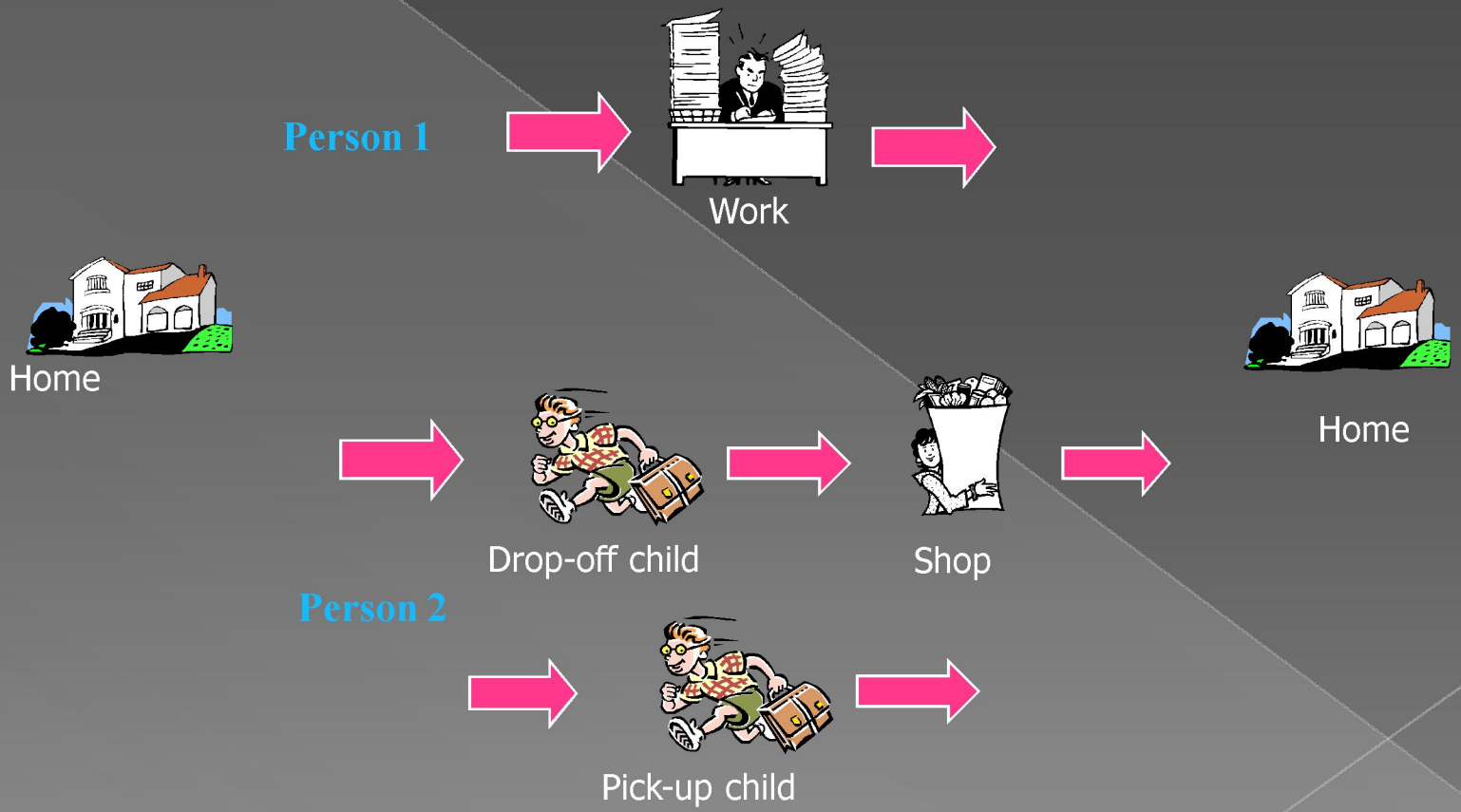
Critique of the Trip-based Approach: Measurement & Modeling

Example 3: Air Quality Effects



Critique of the Trip-based Approach: Measurement & Modeling

Example 4: Inter-personal dependencies and Indirect effects



Contrasting Trip-based and Activity-based Methods: Summary of Conceptual Differences

Trip-based

- ✓ Individual trip is the unit of analysis
- ✓ Internal consistency of the travel pattern NOT guaranteed
- ✓ Impacts of personal and household constraints not captured
- ✓ Time-of-day of travel is not captured adequately

Activity-based

- ✓ Activity-travel pattern is the unit of analysis
- ✓ Ensures internal consistency of the activity-travel pattern
- ✓ Accommodates the impacts of various constraints on activity-travel decision making
- ✓ Models travel within the context of overall daily time-use (both durations and time-of-day)

Contrasting Trip-based and Activity-based Methods: Summary of Modeling Differences

Trip-based	Activity-based
Number of HB and NHB trips	Generation and sequencing of activities
Zonal-level trip attractions & gravity model for trip-end locations	Location of activity participation
Mode for each trip	Mode for linked trips (tours)
Time of day using peak and off-peak factors	Duration and timing of activities and travel

Activity-based Modeling Methods

Unlike the trip-based approach, there is no one single activity-based modeling methodology….

- ✓ CEMDAP (Dallas),
- ✓ FAMOS (Tampa Bay),
- ✓ TranSIMS (Portland),
- ✓ TLUMIP (Oregon),
- ✓ ALBATROSS (Dutch ministry of transport),
- ✓ ARC (Atlanta),
- ✓ TASHA (Toronto),
- ✓ SACSIM (Sacramento),
- ✓ New York Model,
- ✓ Columbus Model, and
- ✓ Denver Model

Modeling Household Inter-personal Interaction

Is the Inter-personal Interaction a matter within a Travel Demand Framework?

- Household members often interact with each other during their daily activity- and travel-related decision-making process
- The decision-unit is the individual, not the household
- Individual-level models are incapable of handling those complex responses (split into individuals, yet still interrelated)
- Individual-level models could over-estimate travel demand (i.e., joint case)
- Joint activity participation and shared rides are outcomes of interacted decision-making
  - 1/3 ~ ½ of observed weekdays tours involved intra-household joint travel (Vovsha et al, 2003)

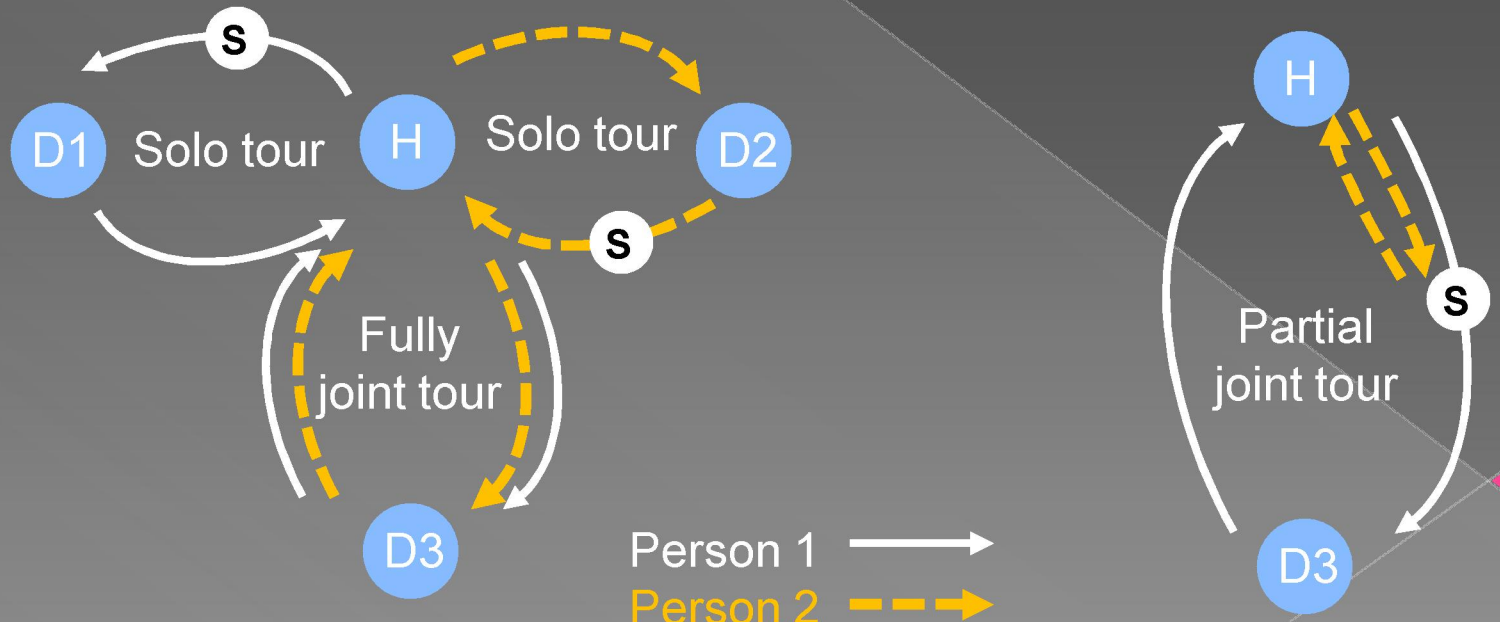
Data Compromising: Sample Break-down

- Florid add-on samples from 2009 National Household Travel Survey (HNTS) is used.
- Limiting to "**Social-Recreational**" tour purpose
- Removes the households while compromising samples if:
  - ✓ Whose members are not completely interviewed
  - ✓ A tour was not started either at home or back to home
  - ✓ Missing key variables (such as income, travel time records, trip purposes, and trip mode chosen, etc.)

Data Compromising:

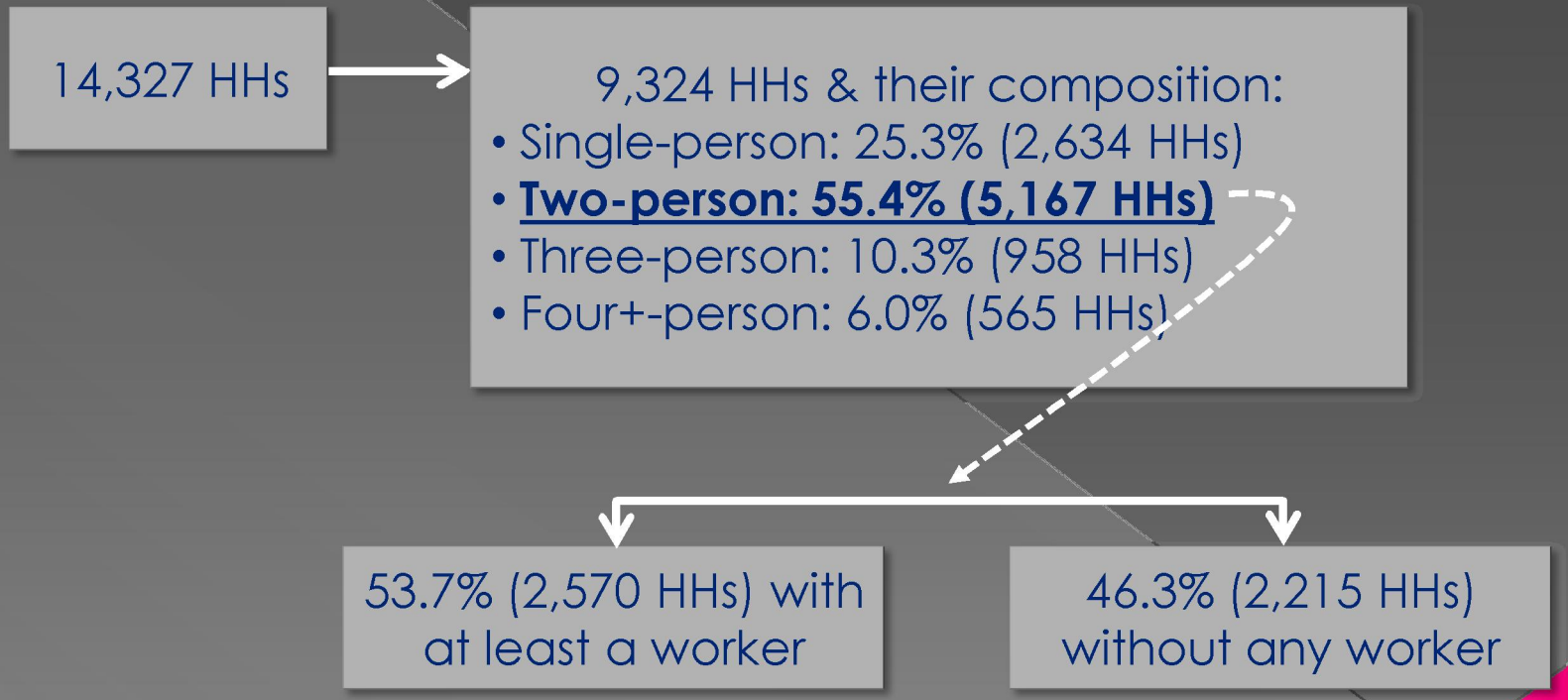
Solo, Fully Joint and Partial Joint Tours

- Tour types: Solo, Fully joint, and Partial joint tour by considering time and space, and travel parties
- A “Fully joint tour” must have the same travel parties, travel time records, and the same locations over the entire trip chain



Data Compromising: Applicable samples

- Used Florida add-on data from 2009 National Household Travel Survey



- 8,298 (26.8%) social-recreational tours (out of 30,984 tours):

  6577 (79.2%) solos, 1523 (18.4%) fully joints, 198 (2.4%) partial joint tours

Data Compromising: Applicable samples

Alternatives	Descriptions	Number of HHs	Percent
000	**No social-recreational tour**	**2565**	**53.61**
001	**1 joint tour**	**269**	**5.62**
002	2 joint	23	0.48
010	**1 female-solo tour**	**548**	**11.45**
011	1 female-solo & 1 joint	29	0.61
012	1 female-solo & 2 joint	2	0.04
020	2 female-solo	78	1.63
021	2 female-solo & 1 joint	5	0.10
100	**1 male-solo tour**	**558**	**11.66**
101	1 male-solo & 1 joint	42	0.88
102	1 male-solo & 2 joint	4	0.08
110	1 male-solo & 1 female-solo	354	7.40
111	1 male-solo & 1 female-solo & 1 joint	26	0.54
112	1 male-solo & 1 female-solo & 2 joint	1	0.02
120	1 male-solo & 2 female-solo	70	1.46
121	1 male-solo & 2 female-solo & 1 joint	3	0.06
200	2 male-solo	108	2.26
201	2 male-solo & 1 joint	5	0.10
210	2 male-solo & 1 female-solo	59	1.23
211	2 male-solo & 1 female-solo & 1 joint	4	0.08
220	2 male-solo & 2 female-solo	29	0.61
221	2 male-solo & 2 female-solo & 1 joint	2	0.04
222	2 male-solo & 2 female-solo & 2 joint	1	0.02
Total		4785	100%

Model Specification: Overall Approaches

- Two broad approaches to operate inter-personal interactions within a choice-modeling framework based on a decision-making unit (i.e., entire household or each household member), and a choice set must be identical regardless of the decision-making unit
- Household-based models
  - ✓ Multinomial logit (MNL)
  - ✓ Multi-linear logit (MLL)
- Household member-based models
  - ✓ Multivariate ordered probit (MOP)
  - ✓ Parallel constrained choice logit (PCL)

Model Specification: Sets of Choice Alternatives based on decision-making unit

- **"Household-based":** 8 choice alternatives {N, M, F, J, MF, MJ, FJ, MFJ}

Activity Participation pattern	N	M	F	J	MF	MJ	FJ	MFJ
Worker-households (2,570)								
Number of households	1,469 (57.2%)	353 (13.7%)	358 (13.9%)	115 (4.5%)	226 (8.8%)	18 (0.7%)	15 (0.6%)	16 (0.6%)
Non-worker-households (2,215)								
Number of households	1,096 (49.5%)	313 (14.1%)	268 (12.1%)	177 (8.0%)	286 (12.9%)	33 (1.5%)	20 (0.9%)	22 (1.0%)

- **"Household member-based":** 3 choice alternatives {N, S, J}
  - ✓ S= Solo social/recreational activity by either male or female

Model Specification: Sets of Choice Alternatives based on decision-making unit

- ✓ Alternative "010"
  - Household: Female-solo activity (F)
  - Male-adult: No social-recreational activity (N)
    Female-adult: Solo activity (F)
- ✓ Alternative "111"
  - Household: Both-solo & Joint activity (MFJ)
  - Male-adult: Solo & Joint activity (MJ)
    Female-adult: Solo & Joint activity (FJ)

- ❑ 8 choice alternatives at "**Household-based**": {N, M, F, J, MF, MJ, FJ, MFJ}
- ❑ 3 choice alternatives at "**Household member-based**": {N, Solo, J}

Model Specification: MNL Model (Household-based)

- **MNL model**: directly express the household utility as a function of the relevant explanatory factors including the characteristics of each of the household members

$$U_i^h = \alpha_i + \beta_{ik} X_{ik}^h + \varepsilon_i^h$$

$$Pr^h(i) = \frac{exp\,(U_i^h)}{\sum_i exp\,(U_i^h)}$$

β_{ik} = Coefficients corresponding to the kth attribute of alternative *i* in household *h*.

ε_i^h = Residual error to the alternative *i* for household *h*.

Model Specification: MLL Model (Household-based)

❑ **MLL model**: represents group decision-making behavior. The household utility for an alternative is constructed as a weighted sum of the individual's utilities and their pair-wise products (Keeney and Kirkwood,1975)

$$U_i^h = \sum_{p=1}^{n} w_{pi}^h u_{pi}^h + \lambda \sum_{\substack{p=1 \\ p'>p}}^{n} w_{pi}^h w_{p'i}^h u_{pi}^h u_{p'i}^h + \cdots + \lambda^{n-1} w_{1i}^h w_{2i}^h \ldots w_{ni}^h u_{1i}^h u_{2i}^h \ldots u_{ni}^h$$

$$U_i^h = \alpha_i + w_m^h u_{mi}^h + w_f^h u_{fi}^h + \lambda (w_m^h w_f^h u_{mi}^h u_{fi}^h) + \varepsilon_i^h$$

⇒ Iff $w_m{}^h = w_f^h$ & $\lambda = 0$ then, collapse to the MNL model

$$u_{mi}^h = \sum_k \beta_{mik} X_{mik}^h$$

$$u_{fi}^h = \sum_k \beta_{fik} X_{fik}^h$$

$$w_m^h = \frac{exp\,(\sum_l \beta_{ml} X_{1l}^h)}{1 + exp\,(\sum_l \beta_{ml} X_{ml}^h)}$$

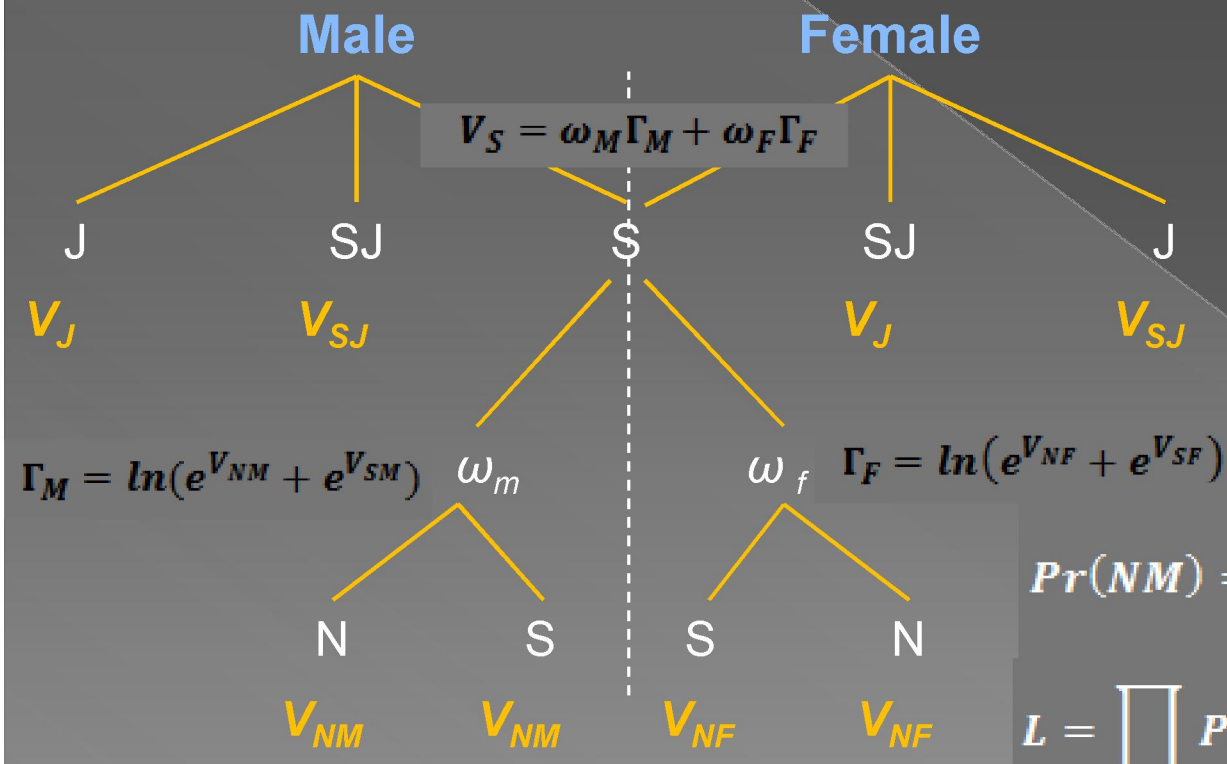
$w_m{}^h$ = male's weight parameter for household h

$u^h{}_{mi}$ = utility of male to alt. i for household h

λ = interaction parameter

Model Specification: PCL Model (Household member-based)

❑ **PCL model**: represent each decision maker's decisions simultaneously by constraining between joint and independent activity participations, and by ensuring that predicted shares of joint activity outcomes be the same for both decision makers (John Gliebe & Frank Koppleman, 2002).



$$Pr(J) = \frac{e^{V_J}}{e^{V_J} + e^{V_{SJ}} + e^{V_S}}$$

$$Pr(NM) = (Pr_{NM}|Solo) \times Pr(S)$$

$$Pr(NM) = \frac{e^{V_{NM}}}{e^{V_{NM}} + e^{V_{SM}}} \times \frac{e^{V_S}}{e^{V_J} + e^{V_{SJ}} + e^{V_S}}$$

$$L = \prod_{i \in C_M} Pr_{iM}^{\delta_{iM}} \times \prod_{i' \in C_F} Pr_{i'F}^{\delta_{i'F}}$$

Model Specification: MOP Model (Household member-based)

❑ **MOP model**: splits each decision maker's choices explicitly and combines their choices by interrelating to represent a joint decision-making process

- ✓ Male's Activity Patterns= {N, S, J}"
- ✓ Female's Activity Patterns= {N, S, J}

→

- ✓ Male-Solo Activity= {N, S}"
- ✓ Female-Solo Activity= {N, S}
- ✓ Joint Activity= {N, J}

$$Pr(i_m i'_f i''_j) = Pr(U_m^h > 0, U_f^h > 0, U_j^h > 0)$$

$$= Pr(\beta_{mk} x_{mk} + \varepsilon_m > 0,\ \beta_{fk} x_{fk} + \varepsilon_f > 0,\ \beta_{jk} x_{jk} + \varepsilon_j > 0)$$

$$= Pr(\varepsilon_m > -\beta_{mk} x_{mk},\ \varepsilon_f > -\beta_{fk} x_{fk},\ \varepsilon_j > -\beta_{jk} x_{jk})$$

$$= \int_{-\beta_{mk} x_{mk}}^{\infty} \int_{-\beta_{fk} x_{fk}}^{\infty} \int_{-\beta_{jk} x_{jk}}^{\infty} \emptyset(\varepsilon_m, \varepsilon_f, \varepsilon_j;\ \rho_{mf}, \rho_{mj}, \rho_{fj}) d_{\varepsilon_m} d_{\varepsilon_f} d_{\varepsilon_j}$$

$$= \int_{\infty}^{(2\delta^{i}-1)\beta_{mk} x_{mk}} \int_{\infty}^{(2\delta^{i'}-1)\beta_{fk} x_{fk} \infty} \int_{\infty}^{(2\delta^{i''}-1)\beta_{jk} x_{jk}} \emptyset(\varepsilon_m, \varepsilon_f, \varepsilon_j;\ \rho_{mf}, \rho_{mj}, \rho_{fj}) d_{\varepsilon_m} d_{\varepsilon_f} d_{\varepsilon_j}$$

Analysis Results: Summary Statistics of Key Variables

- **7 explanatory variables** used in modeling:
  - ✓ 3 socio-economic descriptors (household income, vehicle share, age by gender)
  - ✓ 2 specific activity type engagement descriptors (mandatory activity, maintenance activity)
  - ✓ 1 temporal descriptor (day of traveled)
  - ✓ 1 weather condition descriptor (rained or not)

Analysis Results: Summary Statistics of Key Variables

Variables	Worker-Households	Non-worker households
	Mean	Mean
Household Characteristics		
Household income (1-18, $ 5K interval)	13.09	10.14
Presence of children		
Child (age≤4)/No child	0.09/0.91	0.00/1.00
Vehicle share (vehicle/driver)		
Vehicle Share <1 / Vehicle Share ≥1	0.08/0.92	0.29/0.71
Member Characteristics		
Age		
Male	56.60	72.69
Female	55.15	70.14
Daily duration of hours for maintenance activities		
Male	0.62	0.92
Female	0.80	0.98
Daily duration of hours for discretionary activities		
Male	1.05	1.29
Female	1.00	1.32
Whether engaged in maintenance activities		
Yes/No (male)	0.53/0.47	0.69/0.31
Yes/No (female)	0.58/0.42	0.68/0.32
Number of observation (households)	2,570	2,215

Analysis Results: MNL Model for Worker-households

- 20% samples leave for model validation tests through the modeling (defined "Other" as a base case)

	N (none)		M (male only)		F (female only)		J (joint only)		MF (both independ.)	
Variable	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Constant	3.165	12.84	1.479	6.23	1.455	4.79	1.263	5.20	1.041	4.51
Household (HH) characteristics										
HH income	-0.055	-4.96			-0.029	-1.87				
Age of male										
Age of female										
Engagement of specific activity type										
Mandatory activity of male	1.156	4.65	0.579	2.12	1.487	5.46			0.547	1.86
Mandatory activity of female	0.641	5.32	0.662	3.96			-0.842	-2.49		
Maintenance activity of male										
Maintenance activity of female			-0.578	-4.37			-0.358	-1.65		
Day of traveled										
On a weekday	0.608	2.91	0.683	2.75	0.635	2.58			0.641	2.47
Weather condition on traveled date										
Rained	0.857	1.71	1.340	2.51	0.878	1.64	1.365	2.15		

Analysis Results: MLL Model for Worker-households

	Variable	N (none)		M (male only)		F (female only)		J (joint only)		MF (both solo)	
		Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
	Constant	2.167	7.04	1.921	8.67	1.030	5.33	1.693	6.71	1.265	6.27
Male-head	*Household (HH) characteristics*										
	HH income										
	Age	0.019	2.86								
	Engagement of specific activity type										
	Mandatory activity	2.132	5.48	1.125	2.88	2.892	6.46			1.064	2.44
	Maintenance activity										
	Day of traveled										
	On a weekday										
	Weather condition on date traveled date										
	Rained										
Female-head	*Household (HH) characteristics*										
	HH income										
	Age										
	Engagement of specific activity type										
	Mandatory activity	3.360	5.50	2.644	5.53					1.272	2.41
	Maintenance activity	-0.685	-1.71	-1.921	-4.76			-1.501	-2.25		
	Day of traveled										
	On a weekday										
	Weather condition on date traveled date										
	Rained										
Variable for weight parameter of member in joint decision											
	Full-time job	0.771	3.08								
	Intra-household interaction	-0.278	-3.33								

Analysis Results: MNL Model for Non-Worker-households

	N (none)		M (male only)		F (female only)		J (joint only)		MF (both independ.)	
Variable	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Constant	3.149	15.80	1.635	7.99	1.596	6.02	1.577	6.25	1.108	5.50
Household (HH) characteristics										
HH income	-0.071	-6.24			-0.046	-2.63	-0.054	-2.82		
Age of male										
Age of female										
Engagement of specific activity type										
Maintenance activity of male	0.615	5.78								
Maintenance activity of female			-0.601	-4.25						
Day of traveled										
On a weekday			0.430	2.64	0.374	2.16			0.469	2.70
Weather condition on traveled date										
Rained										

Analysis Results: MLL Model for Non-worker-households

	Variable	N (none)		M (male only)		F (female only)		J (joint only)		MF (both solo)	
		Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
	Constant	3.137	15.76	1.651	8.10	1.591	6.01	1.557	6.17	1.098	5.44
Male-head	*Household (HH) characteristics*										
	HH income	-0.070	-6.19			-0.042	-2.60	-0.052	-2.75		
	Age										
	Engagement of specific activity type										
	Maintenance activity	1.233	5.80								
	Day of traveled										
	On a weekday			0.417	2.56	0.367	2.13			0.476	2.74
	Weather condition on date traveled date										
	Rained										
Female-head	*Household (HH) characteristics*										
	HH income	-0.070	-6.19			-0.042	-2.60	-0.052	-2.75		
	Age										
	Engagement of specific activity type										
	Maintenance activity			-1.234	-4.37						
	Day of traveled										
	On a weekday			0.417	2.56	0.367	2.13			0.476	2.74
	Weather condition on date traveled date										
	Rained										
Variable for weight parameter of member in joint decision											
	Maintenance activity	-	-								
Intra-household interaction		-	-								

Analysis Results: PCL Model for Worker-HHs, defined "Solo+Joint" as a base

Variable	Gender	Parameter	Parameter	t-stat
Constant	Male	**None**	5.502	3.53
		Solo	4.810	3.06
		Joint	4.152	2.66
	Female	**None**	4.906	2.16
		Solo	4.174	1.83
		Joint	2.734	1.91
Family income	Male	**None**	-0.133	-2.35
		Solo	-0.096	-1.68
		Joint		
Age	Male	**None**		
		Solo		
		Joint	-0.039	-1.98
Mandatory activity	Male	**None**	1.878	2.94
		Solo	1.155	1.79
		Joint		
	Female	**None**	3.821	4.44
		Solo	3.204	3.7
		Joint		
Week	Male	**None**		
		Solo	0.855	1.64
		Joint		
	Female	**None**		
		Solo		
		Joint	-0.695	-1.69
Rain	Female	**None**	4.900	2.01
		Solo	4.506	1.84
		Joint		
Variable for weight parameter		Full-time job	1.941	3.66

Analysis Results: MOP Model for Worker-households

Response	Variable	Parameter	t-stat
Solo tour by male	Constant	0.240	0.85
	Household income	0.035	5.43
	Age of male	-0.014	-3.14
	Age of female		
	Maintenance activity by male	-0.300	-4.31
	Maintenance activity by female	-0.152	-2.2
	Weekday	0.183	2.53
	Rained		
Solo tour by female	Constant	0.126	0.44
	Household income	0.026	3.95
	Age of male		
	Age of female	-0.014	-3.11
	Maintenance activity by male	-0.290	-4.11
	Maintenance activity by female		
	Weekday	0.199	2.69
	Rained	-0.355	-2.17
Joint tour by both	Constant	-1.098	-3.11
	Household income		
	Age of male		
	Age of female		
	Maintenance activity by male		
	Maintenance activity by female		
	Weekday	-0.131	-1.64
	Rained		
Error correlation	Rho (male-solo vs. female-solo)	0.448	12.41
	Rho (male-solo vs. joint)	-0.204	-3.83
	Rho (female-solo vs. joint)	-0.196	-3.56

Analysis Results: Goodness-of-fit Comparisons

Samples	Goodness-of-Fit	MNL model	MLL model	PCL model	MOP model
Worker-HHs	# Households	2,570	2,570	2,570	2,570
	LL(β)	-3,188.6	-3,148.6	-3,229.7	-2,612.3
	LL(c)	-3,328.8	-3,328.8	-3,049.5	-2,551.6
	R^2	0.042	0.054	0.056	0.023
Non-worker-HHs	# Households	2,215	2,215	On process	On process
	LL(β)	-3,133.3	-3,110.4		
	LL(c)	-3,236.3	3,236.3		
	R^2	0.032	0.039		

Analysis Results: Behavioral Summary Resulted from MNL & MLL Models

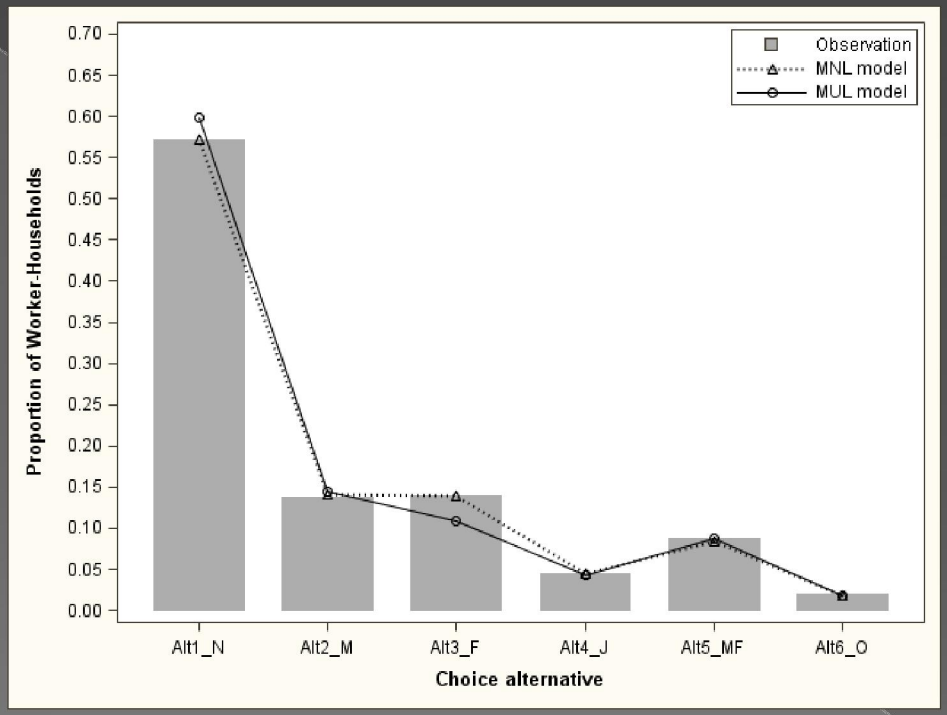
- **Weight effects on the decisions of social-recreational activity participation**:
  - ✓ Worker household group: 0.684 for the male with full-time job as opposed to his counterpart
  - ✓ Non-worker household group: no significant decision-power effects between the couple
- **Intra-household interaction effects**:
  - ✓ Worker household group: utility increase (decrease) of an option for an individual does not imply a corresponding increase (decrease) in the overall utility of the household for that option
  - ✓ Much clear interaction effects from MOP model (error correlation parameters)

    - "+ tive" (male-solo vs. female-solo), "- tive" (male-solo vs. joint & female-solo vs. joint)
  - ✓ Non-worker household group: no evidence of interaction effects

Analysis Results: Behavioral Summary from MNL & MLL Models

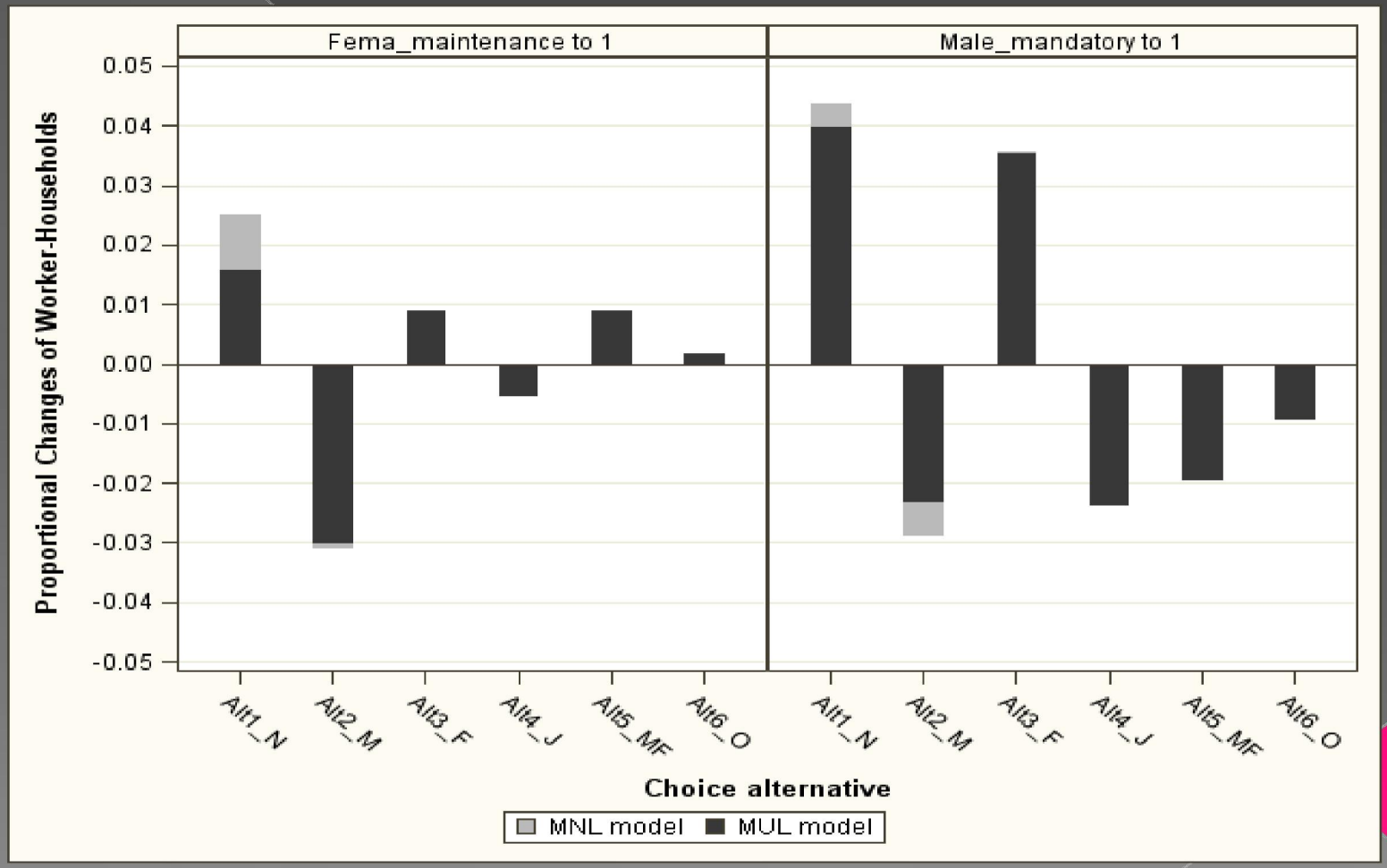
Explanatory Var.	Worker-households	Non-worker-households
HH income	Higher HH income→ more soc/rec activities, but less female solo activity	Higher HH income→ more soc/rec activities, but less female's solo & joint activities
Age of male	More aging, less participation	-
Mandatory activity (male)	Less soc/rec activities by pursuing more independently	-
Mandatory activity (female)	Less soc/rec activities, more likeliness of male's solo participation and less joint episode	-
Maintenance activity (male)	-	Less soc/rec activities
Maintenance activity (female)	Less joint episodes, but more likeliness of soc/rec activities	Less male-solo activities
Day of traveled	Less soc/rec activities during the weekday, and encourages more solo activities	More solo activities during the weekdays
Presence of rained	Less soc/rec activities on the date of rained. Tries to synchronize travel parties to more compact fashions (i.e., male or female solo, or both jointly)	-

Predictive Validations and Sensitivity Tests: Based on MNL & MLL Model Analysis



Comparable Measures	MNL model	MLL model
Mean absolute error	0.091	5.85
Predictive LL	-662.8	-669.7
Vuong test (Z stat.)	1.279 against MLL model	

Predictive Validations and Sensitivity Tests: Based on MNL & MLL Model Analysis



Conclusions

- MNL and MLL models provide reasonable similar predictions
- Household interdependencies and their decision relative importance are affected by household-worker status
- The effects of household interactions and the weights were not observed for the non-worker-household group, implying that household heads are equally powerful in determining social-recreational choices

  → MLL model collapses to the standard MNL model

- Rainfall affected both the intent of social-recreational activity participation and its pattern for the worker-household group
- MLL model could be more favored to the MNL model due to the explicit explainability of individual's different preferences (i.e., different sign on the utility functions and weight impact)

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