# Consumer Surplus Evaluation
# With and Without Integrated Land Use Models

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**This paper was prepared in response to an article in the ITE Journal of September 2005 that challenged the validity of traditional transportation project cost benefit analysis based on models with fixed land use inputs.**

**This report:**

**1. Describes the economics of traditional fixed land use models**

**2. Summarizes the critique of the traditional approach**

**3. Develops an integrated variable land use - transport sketch model**

**4. Shows a side by side comparison of the fixed and variable land use models**

**5. Compares a sketch model evaluation of a road improvement project using the fixed and variable land use methods**

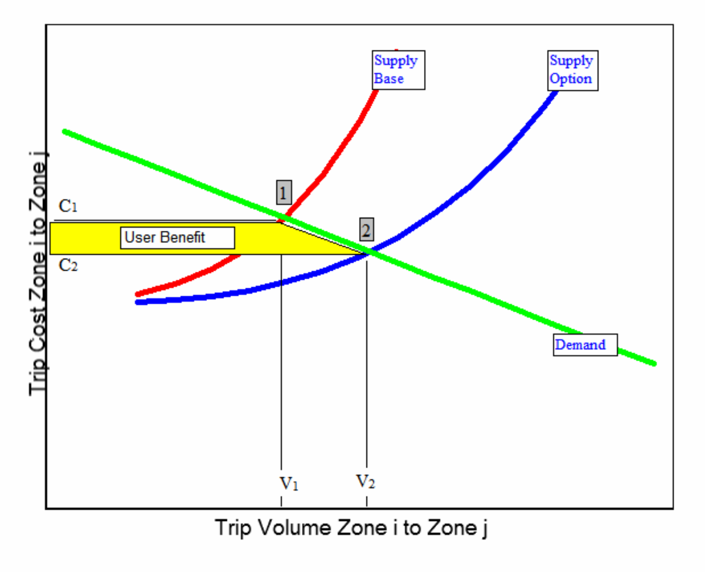
**6. Confirms the general validity of the traditional fixed land use procedure**

# 1. The Economics of Traditional Fixed Land Use Models

**The economics of a traditional four stage fixed land use model are illustrated below, which shows the travel market for trips from any zone i to any other zone j.**

**The Travel Demand** curve is produced in the trip generation, distribution, and mode split stages, and expresses the trip volume as a function of the trip cost.

**The Travel Supply** curve is produced in the assignment stage and expresses the trip cost as a function of the trip volume.




**Travel Market Equilibrium** is produced by cycling several times through supply and demand until the curves intersect.

**Project Evaluation** compares the equilibrium points of a new network option with an initial base condition.

The User Benefit is expressed by the shaded area shown.

UB =1/2*(V1+V2)*(C1-C2)

## 2. The Critique of Current Practice

The validity of traditional transportation economic analysis using fixed land use models with the same land use for both the base and the project option has been challenged in an article by *Stuart Ramsey, titled "Of Mice and Elephants", in the ITE Journal September, 2005*.

The main problem with traditional fixed land use models arises from the need to independently input the population and employment data by traffic zone, rather than to solve for them internally as part of an integrated land use transport model.

Ramsey argues that integrated land use transportation models if available would show much lower user benefits for road transportation improvements than those calculated using a fixed land use model, since induced traffic from land use sprawl would cancel out any congestion relief from the initial investment.

In the absence of such models the Ramsey article provides an example using manual land use adjustment procedures to test the potential twinning of the Port Mann Bridge in Greater Vancouver. The results indicate real benefits one-tenth of those measured using standard fixed land use procedures.

The Ramsey example comparing base and road improvement scenarios under different land use conditions, without any land prices or land benefits in the calculations implies that land has no value. This report proposes a simple integrated model that does include these features.

# 3. The Proposed Integrated Variable Land Use Model

This market based model has demand and supply functions for travel and land. Equilibrium occurs at the point the demand and supply functions intersect.

**The Demand Functions** 1. Trips $Ti\text{-}j = f ( Dj, / CTij, CLi )$
2. Land Origins $Oi = \sum_j Ti\text{-}j$

There are two demand functions, the demand for travel and the demand for residential land
The travel demand function expresses the number of trips from any zone i, to any other zone j as a function of the number of destinations in j, and the inverse of the cost of travel from i to j and the cost of land in i. Land demand is defined as the number of origins in any zone i. This is equal to the sum of trips from zone i to all destinations j as shown by the equation:

**The Travel Supply Function** 3. $CTij= f ( Tij/Capij )$

The cost of travel between zone i, and zone j is directly proportional to the number of trips between i and j, and inversely proportional to the capacity of the road from i to j.

**The Land Supply Function** 4. $CLi= f ( Oi/CapLi\ j$

The cost of land in zone i, is directly proportional to the total number of trip origins in zone i and inversely proportional to the capacity of the land area in zone i.

This is a residential location model that solves for the number of origins Oi or workers in each zone. The **Trip Destination** Dj,s are given, and assumed to be a function of industrial location factors.

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In the variable land use model the number of trip origins in each zone are solved for internally. The chance that someone will make a trip from zone i to zone j depends on the number of destination opportunities in zone j, and the cost of travel from i to j. But it also depends on the probability that the person will live in zone i in the first place, and this is partly a function of the cost of living in zone i relative to zone j.

In the variable land use model, **the Cost of Travel and the Cost of Land are converted to common units**. For instance, assuming that each worker makes 20 daily commutes or 40 one-way trips a month, monthly rents would be divided by 40 to give the land costs per trip.

On this basis, a one bed room apartment downtown that rents for $1600 per month would have a land cost per trip of $1600/40=$40, and the land cost per trip for renting in the suburbs at $1000 per month would be $1000/40=$25. Under these conditions, a person could save $15 in **land costs per trip** by moving to the suburbs.

Assuming a trip time of half an hour and a commute distance of 20 kilometres, a person with a value of time of $10 per hour and a vehicle operating cost of 15 cents per kilometre would have a **travel cost per trip** of $8. For this person, a move to the suburbs while working in the city would involve a saving of $15 - $8 = $7 per trip. Others with higher values of time, or potentially longer commutes might choose to live downtown, and pay the higher rents.

# 4. A Comparison of the Fixed and Variable Land Use Models

## Traditional Fixed Land Use Model

### Travel Demand

$T_{ij}=a_i*b_j*O_i*Dj*e^{-.05*(CTij)}$

Where:

Tij = number of trips going from zone i to zone j
Oi = number of origin trips generated in zone i
Dj = number of destination trips attracted to zone j

$CT_{ij}$ = cost of travel from zone i to zone j

ai = 1 / Sumj bj * Dj * $e^{-.05*(CTij)}$
bj = 1 / Sumi ai * Oi * $e^{-.05*(CTij)}$

## New Variable Land Use Model

### Travel and Land Use Demand

$T_{ij}=b_j*Dj*e^{-.05*(CTij+CLi)}$
Oi = $\sum_j$ Tij

Tij = number of trips going from zone i to zone j
Oi = number of origin trips generated in zone i
Dj = number of destination trips attracted to zone j

$CT_{ij}$ = cost of travel from zone i to zone j
$CL_i$ = cost of land per trip

bj = 1 / Sumi $e^{-.05*(CTij+CLi)}$

The models are solved in an iterative fashion. The ai and bj variables are abstract balancing coefficients that are solved for internally within the models as part of the iterative procedure.

### Travel Supply (Traditional Fixed Land Use Model)

$CT_{ij}=10+(Tij/TCapij)4$

### Travel Supply (New Variable Land Use Model)

$CT_{ij}=10+(Tij/TCapij)4$

### Land Supply

$CL_i=10+(Oi/LCapi)4$

## 5. A Sketch Model Example

A simple representation of the model is shown on the last page. This involves a city zone A, and a suburban zone B, connected by a single two way route.

A Base Scenario is illustrated on the left side of the page.

A Road Improvement Scenario modelled and evaluated with the current fixed land use practice is shown in the middle panel.

A Road Improvement Scenario modelled and evaluated with the variable land use sketch model is illustrated in the right hand panel

Trip volumes are shown graphically in the top section, and then in tabular form just below. In the base and road improvement scenario options, the land use destinations (trip attractions) are given and fixed at 70 units for zone A, and 30 units for zone B. This reflects common urban development patterns, with a surplus of jobs relative to workers in the downtown core.

Travel Costs and travel capacities are shown in the third section down. In this example, internal unit travel costs A-A and B-B are assumed fixed at 5 units. Road capacities between the zones are given as 15 units in the base scenario, and increased to 20 for the road improvement options.

Land Costs, land capacities, and densities for zones A and B are shown in the second last panel. The land capacity measure reflects a quantitative amount of land, and not an absolute ability to absorb development, so densities can be more or less than unity.

The travel model results shown for this example, in terms of trip volumes, trip costs and land costs are all solved using standard iterative procedures for the fixed and variable land use models described in this report.

**The fixed land use model example** shown in the middle panel uses a doubly constrained land use model similar to the TransLink model. A road capacity increase from B-A lowers the unit travel costs from B-A from 19.07 to 13.56, and results in an increased volume of 27.47 trips compared to the base 26.03 trips. With the total origins in B fixed at 44.34, the number of trips from B to B drops from 18.30 to 16.87. The measured consumer surplus user benefit is 150 units.

**The variable land use model example** shown in the right panel involves the same capacity increase as above. The model starts off with a travel cost decrease on the improved road. The improved travel conditions in this case result in some increased volume of trips from B to A at the expense of trips from B to B as before. However, the improved travel conditions also encourage some people to move from A to B resulting in a final larger trip volume increase, and smaller unit travel cost saving than in the fixed land use model. This results in lower user travel benefits, but increased land use benefits for a net increase in overall user benefits of 164 units. This is higher than the 150 calculated for the fixed land use model.

This sketch integrated transport land use model can also be used to forecast and evaluate land use policy changes without any changes to the transport network. For instance, zoning increases in the city that are not forced on the community, would effectively increase the useable land capacity in the city resulting in a measurable consumer surplus benefit according to this model. Densification through this land supply increasing method has a completely opposite effect on private user community benefits to that achieved by constraining transportation supply. The transport supply constraint approach has an adverse impact on land use benefits, which translates into a housing affordability problem.

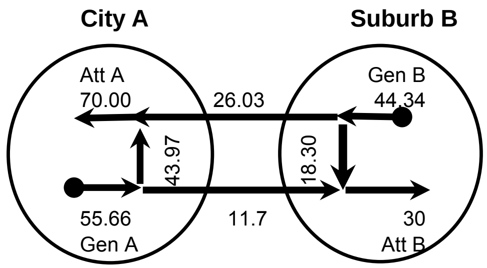
The intention of this sketch model example is, however, not to imply any specific quantitative result to any specific policies, or to claim that an integrated model will always show higher benefits than the current fixed land use models. **The principle aim is to demonstrate that the current imperfect models nonetheless produce accurate and objective analysis of the relative merits of project options that are dramatically better than the manual and subjective adjustments proposed as a replacement.**

## Travel Forecasts and User Benefit Calculations With Fixed and Variable Land Use

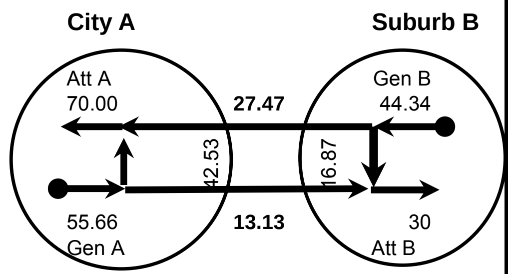
| | Base Scenario | Option: Road Improvement, Fixed Land Use | Option: Road Improvement, Variable Land Use |
|---|---|---|---|

### Trips

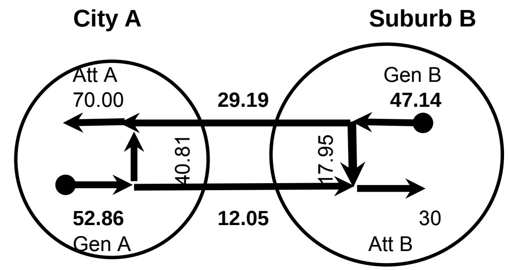
**Base Scenario**




**Option – Road Improvement, Fixed Land Use**




**Option – Road Improvement, Variable Land Use**




### Travel Demand

Trips

**Base Scenario:** $T_{ij}=a_i*b_j*Dj*e^{-.05*(CTij+CLi)}$

| O \ D | A | B | Sum |
|---|---|---|---|
| A | **43.97** | **11.70** | **55.66** |
| B | **26.03** | **18.30** | **44.34** |
| Sum | **70.00** | **30.00** | **100.00** |

**Fixed Land Use:** $T_{ij}=a_i*b_j*O_i*Dj*e^{-.05*(CTij)}$ — **Step 3**

| O \ D | A | B | Sum |
|---|---|---|---|
| A | **42.53** | **13.13** | **55.66** |
| B | **27.47** | **16.87** | **44.34** |
| Sum | **70.00** | **30.00** | **100.00** |

**Variable Land Use:** $T_{ij}=a_i*b_j*Dj*e^{-.05*(CTij+CLi)}$ — **Step 3**

| | A | B | Sum |
|---|---|---|---|
| A | **40.81** | **12.05** | **52.86** |
| B | **29.19** | **17.95** | **47.14** |
| Sum | **70.00** | **30.00** | **100.00** |

### Travel Supply

Travel Cost

**Base Scenario:** $CT_{ij}$=10+(Tij/TCapij)4

| O \ D | A | B | |
|---|---|---|---|
| A | 5.00 | 10.37 | |
| B | 19.07 | 5.00 | |

Assumptions: **$Tcap_{ab}$ = 15** **$Tcap_{ba}$ = 15**

**Fixed Land Use:** $CT_{ij}$=10+(Tij/TCapij)4 — **Step 2**

| O \ D | A | B | |
|---|---|---|---|
| A | 5.00 | **10.19** | |
| B | **13.56** | 5.00 | |

Assumptions: **$Tcap_{ab}$ = 20** **$Tcap_{ba}$ = 20** — **Step 1**

**Variable Land Use:** $CT_{ij}$=10+(Tij/TCapij)4 — **Step 2**

| | A | B | |
|---|---|---|---|
| A | 5.00 | **10.13** | |
| B | **14.54** | 5.00 | |

Assumptions: **$Tcap_{ab}$ = 20** **$Tcap_{ba}$ = 20** — **Step 1**

### Land Supply

Land Cost

**Base Scenario:** $CL_i$=10+(Oi/LCapi)4

| | | LCost | Density |
|---|---|---|---|
| A | | 13.75 | 1.39 |
| B | | 10.16 | 0.63 |

Assumptions: **$Lcap_a$ = 40** **$Lcap_b$ = 70**

**Variable Land Use:** $CL_i$=10+(Oi/LCapi)4 — **Step 4**

| | | LCost | Density |
|---|---|---|---|
| A | | **13.05** | 1.32 |
| B | | **10.21** | 0.67 |

**$Lcap_a$ = 40** **$Lcap_b$ = 70**

### User Benefits

**UB=1/2(T1+T2)*(C1-C2)**

**Fixed Land Use:** — **Step 4**

| O \ D | A | B | | Total |
|---|---|---|---|---|
| A | **0** | **2** | | **2** |
| B | **147** | **0** | | **147** |
| Sum | **147** | **2** | | **150** |

**Variable Land Use:** — **Step 5**

| O \ D | A | B | Land | Total |
|---|---|---|---|---|
| A | **0** | **3** | **38** | **41** |
| B | **125** | **0** | **-2** | **123** |
| Sum | **125** | **3** | **36** | **164** |