On Joint Rail and Property Development: Opportunities and Potential Pitfalls

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Facts and figures

- Population: ~ 7 million
- Total area: 1104 km², about 20% land developed
- Urban density: 34,000 persons/km²
- In comparison: LA - 3,144; Tokyo - 7,100
- 12 million daily PT trips, ~90% of all trips
- Mean journey time: 39 minutes, over 50% within 30 minutes
Background

• Mass transit railway services
  – Safe, improve mobility, avoid congestion, etc.
  – Ideal if financially sustainable, with affordable fares and expedient quality
  – The case of Hong Kong: all rail services are provided under prudent commercial principles, renowned for high quality and profitability, often considered as a benchmark for urban rail transit projects

Public Transport in Hong Kong

• Public Transport in HK involves a multi-modal network
  – Railways (MTR, LRT)
  – Franchised Buses (over 600 routes)
  – Red and green Minibuses (hundreds of routes)
  – Taxi, ferries, tram, peak Tram
• All modes are financially sustainable without direct government subsidy
Modal Split
Supply of transit services

<table>
<thead>
<tr>
<th></th>
<th>Hong Kong</th>
<th>London</th>
<th>Singapore</th>
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<tbody>
<tr>
<td>Rail car-km (million)</td>
<td>255</td>
<td>414</td>
<td>89</td>
</tr>
<tr>
<td>Bus vehicle-km (million)</td>
<td>513</td>
<td>450</td>
<td>299</td>
</tr>
<tr>
<td>Population (million)</td>
<td>6.9</td>
<td>7.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Rail car-km per capita</td>
<td>37.0</td>
<td>56.3</td>
<td>21.0</td>
</tr>
<tr>
<td>Bus vehicle-km per capita</td>
<td>74.4</td>
<td>61.2</td>
<td>70.5</td>
</tr>
<tr>
<td>Combined rail car and bus vehicle-km per capita</td>
<td>111.4</td>
<td>117.5</td>
<td>91.5</td>
</tr>
<tr>
<td>% total passenger-km on mass public transit</td>
<td>82%</td>
<td>30%</td>
<td>47%</td>
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Land-use and Transport Policy in Hong Kong

1. The policy on land development
2. The Policy of Limiting Private Car Ownership and Usage
3. The Policy of Transit Service Coordination and Protection (1980’s)
4. The Policy of Service Proliferation and Competition (1990’s)
5. The Policy of Service Rationalization and Consolidation (2000’s)

Policy on Land Development

- Scarcity of land and expanding population form a catalyst for high density development sustaining over the years.
- Developments of the existing central business districts around the Victoria Harbor generate tremendous converging traffic demand.
- High-density residential estates, or new towns, built around railway stations form large passenger bases to support mass transit railways and their financial sustainability.

Example: TKO new town
Example: TKO new town

The total development area of TKO is about 10.05 km², with a population of around 350,000. The average density is 35,000 per km².

Policy of Limiting Private Car Ownership and Usage

- Passenger car ownership: 56 per 1000 people; US: 439; Singapore: 121; Chile: 118 (World Bank Data 2009)
- New private cars are subject to the first registration tax from 35% to 100% of the vehicle cost
- High fuel tax: Unleaded gas in Hong Kong is ~ HK$15/liter or RMB 6/liter
- Private car trips constitute 10% of total daily passenger trips, as compared with 95% in the US.
Transit service coordination and protection (1980s)

- Higher priority given to off-street public transit
- Rapid development of rail transit services, with protection against direct competition from other modes
- Allowed the creation of a win-win situation; the Govt could rely on the private sector to provide for services based on the user-pay principle without subsidy
- But later criticized as protecting the existing sizeable operators and unable to motivate their service improvement

Service proliferation and competition (1990s)

- Encourage “healthy” competition between modes
  - Remove the protection policy for the rail mode
  - Massive expansions of both rail and bus services
- This policy was initially welcome, but at the expense of:
  - Congestion externality – oversupply of buses on profitable corridors
  - Financial difficulties for operators – the demand was spread too thin due to oversupply of services
Policy of service rationalization and consolidation (2000’s)

- The Government outlined future transport strategies: (1) better integration of transport and land use, (2) better use of railway as the backbone, (3) better use of ITS, etc.
- One objective was to increase rail-based PT journeys from 33% to 40% ~ 50% in 2016.
- Plans for bus service consolidation were strongly objected by local districts; this policy were not welcome and resisted at every step of the way.
- In the end, once a public transport service is offered, it is extremely difficult to consolidate its service.

Impacts of Transport Policies

Rail and bus services supply and utilization rate

- Rail car-km/capita
- Bus veh-km/capita
- Rail passenger trips per rail car-km
- Franchised bus passenger trips per bus vehicle-km
- Rail car-km per capita
- Franchised bus vehicle-km per capita
- Rail passenger trips per capita
- Franchised bus passenger trips per capita
- Combined rail + franchised bus passenger trips per capita
Rail transit development model in Hong Kong

- Fund, build and operate the railway, and pay back dividend
- Define legal framework, derive policies, drive and monitor railway development, and grant land for property development
- Share property development profit
- Form joint venture to develop property
- Contribute to economic growth
- Regulate land use and town planning

Costs and revenues of MTR

- Total Operating Cost after depreciation
- Total Operating Cost before depreciation
- Total Income including property profit
- Fare Revenue
- Turnover

Graph showing costs and revenues from 1984 to 2004.
## Profitability of Operators

<table>
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<tbody>
<tr>
<td>Operating margin before tax</td>
<td>6.0%</td>
<td>14%</td>
</tr>
<tr>
<td>Operating return on net fixed asset</td>
<td>0.7%</td>
<td>14%</td>
</tr>
<tr>
<td>Total return (including property profit) on net fixed asset</td>
<td>5.1%</td>
<td>N/A</td>
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### Comparison of Operating Costs

<table>
<thead>
<tr>
<th>Average operating cost (HK$)</th>
<th>MTR (rail)</th>
<th>KMB (bus)</th>
<th>MTR vs KMB (rail vs bus)</th>
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<tbody>
<tr>
<td><strong>Before depreciation &amp; interest</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Per passenger carried (HK$)</td>
<td>3.8</td>
<td>3.8</td>
<td>Similar</td>
</tr>
<tr>
<td>• Per space-km (HK$)</td>
<td>0.09</td>
<td>0.10</td>
<td>10% lower</td>
</tr>
<tr>
<td><strong>After depreciation &amp; interest:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Per Passenger carried</td>
<td>7.2</td>
<td>4.5</td>
<td>60% higher</td>
</tr>
<tr>
<td>• Per space-km (HK$)</td>
<td>0.18</td>
<td>0.12</td>
<td>50% higher</td>
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Analysis for a more general context

• To analyze transport infrastructure development strategies, cross-subsidization between housing market and transportation infrastructure projects, public housing provision, etc.

• To investigate the distribution of costs and returns among different stakeholders.

• To develop an analytical framework for an integrated land use and transport system.

• To study the impact of transport management strategies on residential location choices and the resultant land value.

An integrated land use and transport system...
...modeled by an analytical framework

To achieve... | To be decided... | Stakeholders
---|---|---
System optimization | TS-DM strategies: Network expansion and/or Road pricing, etc. \((y^{i,1}, p^{i,1})\) | Government/Planners (Planning perspective)

A general equilibrium

- Housing provision \(S^{(r)}\) | Developers’ decision
- Residential location \(r\)
- Workplaces \(s\)
- Travel modes \(m\)
- Travel routes \(p\)
- Residents’ location and travel choices

A general equilibrium framework

- Bid-rent Process (who to rent to and the resultant rent)
  - Based on residents’ willingness to pay
  - Auction process
  - Bid-rent at different locations (expected maximum rent)
- Residential location Choice (which location to rent from)
  - Location choice: location accessibility, attractiveness
  - Travel choice: transportation cost
  - Utility maximization
- Developer housing supply problem
  - Bid-rent at different locations
  - Cost of housing supply
  - Profit maximization

Sources:
Combined Residential Location Choice and the Bid-rent Process

- The two choice processes are proven to be consistent and produce identical allocations.
Residential Location Choice

• Consumer Surplus (CS): is expressed as the difference between resident’s willingness-to-pay and the actual rent:

\[ CS^{rsk} = WP^{sk/r} - \varphi^r \]

\[ p_{T,rsk} = \frac{\exp (\beta \cdot CS^{rsk})}{\sum_r \exp (\beta \cdot CS^{rsk})} \]

The number of resident choosing location \( r \):

\[ q^{rsk} = D^{sk} \cdot p_{T,rsk} \]

Combined Residential Location Choice and the Bid-rent Process

\[ p_{T,rsk}^{sk/r} = \frac{\exp (\beta \cdot WP^{rsk})}{\sum_s \sum_k \exp (\beta \cdot WP^{rsk})} \]

\[ q^{rsk} = S^r \cdot p_{T,rsk}^{sk/r} \]

\[ p_{T,rsk} = \frac{\exp (\beta \cdot CS^{rsk})}{\sum_r \exp (\beta \cdot CS^{rsk})} \]

\[ q^{rsk} = D^{sk} \cdot p_{T,rsk} \]

Equilibrium Condition
Developer housing supply choice

• Developers’ decision on housing provision \( S^{(r)} \)
  – Under the principle of profit maximization

\[
Pr^{(r)} = \frac{\exp(\lambda^{(r-n_2)} \cdot \pi^{(r-n_2)} \cdot \exp(\tau))}{\sum_{r=0}^{n_2} \exp(\lambda^{(r-n_2)} \cdot \pi^{(r-n_2)} \cdot \exp(\tau))}, \quad \forall \tau \geq 0, n_2 \geq 1
\]

\[
\pi^{(r-n_2)} = \varphi^{(r-n_2)} - h^{(r-n_2)} \quad \text{Profit}
\]

• Following a quasi dynamic structure

\[
S^{(r)} = \begin{cases} S^{(0)}, & 0 \leq \tau < n_2 \\ S^{(r)} \cdot Pr^{(r)}, & \tau \geq n_2 \end{cases}
\]

Benefit distribution among stakeholders

• The impact of transport supply and demand management on the benefit of
  – heterogeneous income groups of residents
  – housing developers

• General conditions
  – Single time period
  – One OD pair
  – Fixed housing supply
Benefit distribution among stakeholders

- **Proposition – transportation supply**
  - Under conditions
    - \( H_0 \): One OD pair \( r \) and \( s \), households with multiple income groups \( k \)
    - \( H_1 \): One travel route \( p \), travel time reduced by \( \Delta t < 0 \) with investment cost \( B_t \)
    - \( H_2 \): Homogenous value of time, \( \text{vot}^t = \text{vot} > 0 \)
  - Any travel cost reduction due to transport infrastructure improvement, either in time-based or money-based formulation, will lead to an equivalent increase in land or rental value
  - Consumer surplus (household) ➞
  - Housing supplier surplus ➪

Benefit distribution among stakeholders

- **Proposition – transportation supply**
  - Under conditions
    - \( H_2 \) - \( H_3 \)
    - \( H_3 \): Heterogeneous value of time, \( \text{vot}^1 < \text{vot}^2 < \cdots < \text{vot}^k \)
    - \( H_4 \): Money-based travel cost formulation
  - Residents with higher incomes/higher values of time benefit more from transport improvement as compared with residents with lower incomes/lower values of time
  - Consumer surplus (household) ➞ ➞ ➪
  - Housing supplier surplus ➪
Benefit distribution among stakeholders

• Proposition – demand management
  – Under conditions
    • \( H_0 \)– \( H_1 \)
    • \( H_2 \): Heterogeneous value of time, \( vot_1 < vot_2 < \ldots < vot_k \)
    • \( H_3 \): Time-based travel cost formulation
  – Residents with higher incomes/higher values of time benefit more from demand management, e.g. increasing link toll, as compared with residents with lower incomes/lower values of time
  – Consumer surplus (households’)  Lowest  \( \rightarrow \)  \( \uparrow \)  Highest
  – Housing supplier’s surplus  \( \downarrow \)

General equilibrium formulation over time

• A quasi dynamic structure
  – Different time adaptabilities of sub-systems
    • Residents’ travel behavior
    • Residents’ location choice
    • Housing investment
    • Transport/rail infrastructure investment
  – Implying that given a time period \( t \), residents’ location and travel choices are made under a fixed land use and transport system
The problem is formulated as an equivalent Nonlinear Complementarity Problem (NCP)
i.e. to find \( Z' \geq 0 \) such that \( F(Z') \geq 0 \) and \( Z'^T \cdot F(Z') = 0 \)
where,

\[
Z = \begin{cases}
    f_{r,s,m,p,k,t}^{rsk}, & \forall r,s,m,p,k,t \\
    S_{r,t}^{rsk}, & \forall r,t \geq n_2 \\
    b_{k,t}^{rsk}, & \forall k,t
\end{cases}
\]

\[
F(Z) = \begin{cases}
    f_{r,s,m,p,k,t}^{rsk} - q_{r,s,m,p,k,t}^{rsk}, & \forall r,s,m,p,k,t \\
    S_{r,t}^{rsk} - P_{r,t}^{rsk}, & \forall r,t \geq n_2 \\
    \sum_{r} S_{r,t}^{rsk} - P_{r,t}^{rsk} - H_{k,t}^{rsk}, & \forall k,t
\end{cases}
\]

General equilibrium formulation over time

- Maximize social welfare (consumer and producer surpluses)
- Optimal transport management strategies
  - Transport Supply and Demand Management,
  - e.g. Rail link expansion and fare pricing
- Under a time-dependent network following a quasi dynamic structure
- With cost recovery conditions

\[
NPV = \sum_{t} \nu(dr_1, r) \cdot (R_{r}^{rsk} + R_{r}^{rsk}) - \sum_{r} \nu(dr_1, r) \cdot (B_{r}^{rsk} + B_{r}^{rsk}) - \sum_{r} \nu(dr_1, r) \cdot (M_{r}^{rsk} + M_{r}^{rsk}) \geq 0
\]

Producer surplus

Maximize \( SW = \sum_{r} \nu(dr_1, r) \cdot \sum_{r} \sum_{k} q_{rsk}^{rsk} \cdot CS_{rsk}^{rsk} + NPV \)
To summarize...

A general equilibrium

Maximize $SW_{\rho^m, \nu^m}$

TS-DM strategies:
- Network $(y_{ik}^{(\tau)}, \rho_{ik}^{(\tau)})$ or
- Road pricing, etc.

$G(Z) = 0$

Developers’ decision

$\text{Stochastic bid-rent process}$

$\text{Group decision making mechanism}$

To achieve...

To be decided...

Stakeholders

- Quasi dynamic structure
- Cost recovery constraint

Numerical example

- Network
  - Two residential locations 1,2
  - Two workplaces 5,6
  - Seven links
- Demand
  - Two income groups (high & low)
  - Increasing population for each time interval
  - Workplace choices are exogenously given
- Three time intervals $\tau=0, 1, 2$
- Three scenarios
  - Scenario 0: Do-nothing
  - Scenario I: Welfare maximization with TS-DM
  - Scenario II: Welfare maximization with DM alone
Results

• Overall system performance I
  – Transport management strategies increase overall social welfare
  – TS-DM is generally better than DM alone
  – (* transport investment includes both construction cost for new expansions and maintenance cost for all highway links)

Results

• Overall system performance II
  – Travel time reduced through both transport strategies
  – TS-DM is better than DM alone in congestion relief
  – DM alone introduces higher travel costs
  – Consumer surplus reduced
Results

- Overall system performance III
  - The overall producers’ surplus increased
  - \( \text{(Producer’s surplus} = \text{Transport investors’} + \text{Housing developers’}) \)

Sensitivity analysis of transport supply

- Transport investment and Housing market
  - Developer surplus increases monotonically with transportation supply due to increasing housing rents
  - Consumers may benefit or suffer from transportation supply depending on the tradeoff between travel cost reduction and increased housing rents
What about joint rail and property development?

– To what extent one can exploit the synergy between rail and property developments?

• Property development brings in rail patronage, hence higher fare revenue
• Improved accessibility due to rail increases values of properties
• To what extent property value increases can be used to cross-subsidize rail infrastructure development


Joint railway and housing development

Profit function

\[
\begin{align*}
\Pi &= R_H + R_T - B_H - B_T \\
&= \sum_{r} \sum_{\nu} \varphi^\nu \cdot \Psi^\nu (Pr^\nu) + \sum_{r} q_{rs}^{\nu} \cdot cp^{rs} - \sum_{r} b_H^\nu \cdot \Psi^\nu (Pr^\nu) - B_{IC} - st \cdot b_{TD} (hw)
\end{align*}
\]

- $r$ - The housing location
- $\nu$ - The housing type
- $Pr^\nu$ - The proportion of investing housing type $\nu$ in location $r$
- $\Psi^\nu$ - The number of housing type $\nu$ invested in location $r$, $\Psi^\nu (Pr^\nu)$
- $cp^{rs}$ - The railway fare between $rs$
- $hw$ - The operational headway
- $st$ - The number of trains, $st(hw)$
Joint railway and housing development

Mathematical Program with Equilibrium Constraints (MPEC)

Maximize \( \Pi = R_H + R_{\bar{t}} - B_H - B_{\bar{t}} \)

s.t. \( G(Z) = 0 \) ← Gap function for the combined equilibrium

\[ \sum_{r} \sum_{w} P_{r}^{rw} = 1 \]

\[ h_{w} \leq h_{w} \leq \bar{h}_w, \forall r, s \]

\[ c_{p} \leq c_{p}^{rs} \leq \bar{c}_p, \forall r, s \]

Proposition – Effects on Residents

– The travel costs of residents monotonically increase with headway and fare

– Changes in railway investment, e.g. headway or fare, do not change residents’ consumer surplus because any decrease (increase) in transport cost is absorbed by corresponding rent increase (decrease)

– A regressive effect also prevails, high income groups gain more from transport service improvements
Joint railway and housing development

- **Proposition – Effects on Rail + Property Developer**
  - Housing rents monotonically decrease with transport cost increases (e.g. headway and fare)
  - If rail is the only transport mode, the combined producer surplus does not change with fare changes, due to the internal transfer between property and fare revenue.
  - In the presence of a multi-modal network, the combined producer surplus (housing and rail) monotonically decreases with fare. Therefore, the joint developer has incentive to keep fare at a reasonably low level to maintain producer surplus at a high level, since gain from housing revenue offsets reduction in fare revenue.

What about optimal housing supply: the perspective of developer vs residents?

Assumptions:
- \((H_0): A \text{ linear network with two residential locations connected in series to one central CBD. Links 1 and 2 have fixed travel time. Homogeneous housing types are to be developed in origin 1 and/or origin 2} \)
- \((H_1): \text{Homogeneous income class, e.g. } v_{0}^{k} = v_{0} > 0 \)
- \((H_2): \text{Heterogeneous income class, e.g. two income class, } v_{0}^{k_1} > v_{0}^{k_2} \)
- Total Supply is fixed
  - \( S^{k_1} + S^{k_2} = S = 1000 \)

**Developer optimal housing supply strategy**

- **Proposition:** The optimal housing supply for developer:
  - Under \((H_0)\) and \((H_1)\)
    \[
    S^* = S \cdot \frac{\exp(\beta \cdot WP)}{\exp(\beta \cdot WP_1) + \exp(\beta \cdot WP_2)}
    \]
    or \(S^* \rightarrow S\)

- Instead of placing all 1000 units in origin 1, which is closer to CBD, the developer places 200 units in origin 2. Although origin 2 has a higher transport cost and therefore lower rent, doing so the rent in origin 1 will be higher as the supply there is reduced from 1000 to 800. Revenue is maximized when the marginal effects of the two are equal.

- The exact optimal allocation depends on the difference in travel cost, or beta
- At any optimal solution, more housing should be in origin 1 than in origin 2
  - **Create some housing shortage in origin 1**

**Residents optimal housing supply strategy**

- **Proposition:** The optimal housing supply for residents:
  - Under \((H_0)\) and \((H_1)\)
    \[
    S^* \rightarrow 0 \text{ or } S
    \]
  - **Concentrated Development** (all development in origin 1 or 2)
  - Concentrated development pulls down the rent dramatically
  - Consumer surplus is then maximized
Residents optimal housing supply strategy: sensitivity analysis

To analyze the performance of housing revenue and total consumer surplus when housing supply in different locations change.

Assumptions:

- \((H_2)\): Two income classes: High and Low income, e.g. different vot’s and incomes
- The BPR congestion function is used to model links 1 and 2

Results:

- Vary with beta, scaling parameter, and the relative proportions of income groups
  - Case 1: small beta. Choice becomes more random
  - Case 2: large beta. Choice becomes more deterministic

Developer perspective (large beta)

- When the number of high income residents is high, say 700, the optimal housing supply is to provide housing which is slightly less than the number of high income resident, create shortage for high income residents
- When the number of high income resident is low, say 300, increasing the housing supply will result in a higher revenue
- Result is consistent with Proposition 1
- It is not always good to put all housing units in a convenient locations, e.g. origin 1
Residents’ perspective (large beta)

- The maxima occur along the 45 degree line, where the housing supply in origin 1 equals the number of high income residents, or segregation of residents in different locations.
- In origin 2, the rent will not be pulled up by the presence of high income residents.
- On the other hand, low income residents do not need to live in expensive housing units in origin 1.

Summary remarks

- Financial sustainability of rail transit services require accompanying transport and land use policies
  - discourage car ownership, high-density development, priority treatment for rail-based public transport, inter-modal coordination, etc. Privatization is not a panacea.
- Even with these policies, fare revenue alone is extremely difficult to achieve financial sustainability.
- Exploiting the synergy between rail and property development is essential.
Transportation improvements lead to higher willingness-to-pay and hence higher location bid-rents. Developers always benefit from transportation improvements.

Under heterogeneous value of time, higher income groups benefit more from transport improvements, possibly a regressive effect.

Pricing or demand management hurts developers, due to reduced willingness-to-pay and hence lower housing rents.

Transportation improvements may not always benefit consumers, depending on the resultant location bid-rent and reduced travel cost.

A joint rail + property developer has incentive to maintain the rail system at low fare to achieve high producer surplus.

It also permits cross-subsidization between housing and transportation developments, which may achieve win-win solutions.

Modeling of such joint development over time is an interesting and important research topic.
Summary remarks

- Housing revenue maximization is affected by accessibility positively, and by supply effect negatively.
- Under both homogeneous and heterogeneous values of time, revenue maximization leads to housing shortage in convenient locations.
- Under heterogeneous value of time, consumer surplus maximization results in segregation of different income classes at different locations.

Current studies

- Private public partnership (PPP) for joint rail and property development needs to be carefully studied, especially under demand and finance uncertainty.
- Housing-led versus transport-led developments, which one would prevail, under what conditions.

Source:
Discussion