Transport Planning for Disaster Management

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Aerial views of damage caused by Hurricane Sandy along the New Jersey coast on October 30, 2012.

Source: Greenpeace
Aerial views of damage caused by Tsunami, Fukushima on March 11, 2011.

Source: citypictures.org
Crowds form at Transfer Station at Seoul

Source: Korea Times
Outline

• Transport Planning for Disaster Management
  ✓ Evacuation Route Design on Road Networks
    - Methodologies for Route Design
    - Case Study on Tsunami
    - Case Study on Seoul’s Hierarchical Bus Route Design
  ✓ Information Provision Strategy for Dispersion
    - Case study on alternative shortest path provision
  ✓ Furniture Layout Design on Transit Stations
    - Case Study on congested movements
Evacuation Route Design on Road Networks

- Existing Network Design for Evacuation
- Communication Network Design
- Public Transportation Network Design
- Social Organization Network Design
- Multi Agent Transport Simulation
- Assessment of Vulnerability and Criticality
Motivation

Evacuation route planning has become a topic of critical importance due to the recent Tsunami in Japan. Particularly, the network in an urban area where a large number of people live is subject to be negatively affected from such a natural disaster.
**Motivation**

To minimize the damage of natural disaster such as tsunami, an emergency action plan for the vulnerable coast should be developed.

Detour route of the vehicle on the network to support fast efficient traffic network plan is needed.

**Florida and Louisiana, 1992**

- No effective evacuation planning
- Traffic congestions on all highways
- Great confusions and chaos

Source: Hurricane Andrew, 1992 Traffic congestion (www.washingtonpost.com)

Source: Hurricane Evacuation Route Sign in Florida
REVIEW
Evacuation Planner

Linear Programming Approach (1)

- Step 1:
  Convert evacuation network G into time-expanded network GT with user provided time upper bound T.

\[ G : \text{evacuation network with } n \text{ nodes } (n = 4) \]

Evacuation Planner

Linear Programming Approach (2)

- Step 2: Treat time-expanded network $GT$ as a flow network and define the evacuation problem as a minimum cost flow problem on $GT$:

$$
\begin{align*}
\min & \quad \sum_{t=0}^{T} \sum_{i \in D} t x_{id}(t) \\
\text{s.t.} & \quad x_{is}(0) = q_i, \forall i \in S, \\
& \quad \sum_{t=0}^{T} \sum_{i \in D} t x_{id}(t) = \sum_{j \in S} q_j, \\
& \quad y_i(t + 1) - y_i(t) = \sum_{k \in \text{pred}(i)} x_{ki}(t) - \sum_{j \in \text{succ}(i)} x_{ij}(t), \\
& \quad t = 0, \ldots, T; \forall i \in N \\
& \quad y_i(0) = 0, \forall i \in N \\
& \quad y_i(t) = 0, \forall i \in D; t = 0, \ldots, T \\
& \quad 0 \leq y_i(t) \leq a_i, t = 1, \ldots, T; i \in N - D \\
& \quad 0 \leq y_{ij}(t) \leq a_{ij}, t = 0, \ldots, T - \lambda_{ij}; \forall (ij) \in A
\end{align*}
$$

(minimize total evacuation time of all evacuees)

(initial occupancy at source nodes at time 0)

(all evacuees reach destination nodes by time $T$)

- Step 3: Solve above problem using minimum cost flow solvers.

$N$: set of nodes,
$S$: set of sources; $D$: set of destinations,
$q_i$: initial # of evacuees at source node $i$,
$x_{ij}(t)$: flow from node $i$ to $j$ at time $t$,
$y_i(t)$: # of evacuees stay at node $i$ at time $t$,
$a_i$: max. capacity of node $i$,
$b_{ij}$: max. capacity of arc from node $i$ to $j$. 
Hierarchical Network Design Problem

(a) Clusters of Nodes  
(b) Backbone Network

Hierarchy Network Design

Basic concept

Conventional network

Hierarchical network as Corridor and Feeder

Travel time

Origin

Destination

Distance

Feeder Merging Delay

Critical Point

Feeder Diverging Delay

Travel time of Feeder line

Travel time of Corridor line

In-vehicle time of conventional line

vehicle time of Hierarchical line with corridor

Delay time
Shortest Path Strategy: Corridor Line Generation

- Corridor Line Set
  - Search Shortest path from origins to destinations
  - Identify the most overlap common line (Corridor)
  - Find transfer nodes on the corridor line
Shortest Path Strategy: Feeder Line Generation

- Feeder Line Set
- Shortest path from changed origins to changed destinations
Hierarchy Network Design

Well organized

Ill organized

Source: Dr. Jean-Paul Rodrigue, Dept. of Economics & Geography, Hofstra University.
Methodology of Hierarchical evacuation network design

- Clustering
  - Network Clustering by Communication Network Design Method

- Hub Selection
  - Hub Selection by Public Transport Area Method

- Hierarchy Network Configuration
  - Network Hierarchy By Social Organization Area Method

- Corridor Line Generation
  - Case 1: Minimum Distance Rule
  - Case 2: Maximal Flow Rule
  - Case 3: Maximum Accessible Rule
  - Case 4: Minimum Travel Time Rule
Example_Busan, Korea

Background
- After 1900, 4 times of submarine earthquakes occur around Korea
  - When submarine earthquake occurs at the waters of Japan, it can affect Korea
    - May 1983, A 7.7 magnitude submarine earthquake occurs at the waters of Akita, Japan
    - July, 1993, A 7.7 magnitude submarine earthquake occurs at the waters of Okusiri island, Japan
- It takes 100~120 minutes to approach the east and south coast of Korea
- 1 million people in Haeundae, Busan (the south coast of Korea) on holiday season

Network
- Simple main path in the network in Busan
Example_Busan, Korea

Network setting
- Simple main path in the network in Busan
- Each link has a travel cost (time) by BPR function
- Initial node demand is randomly distributed (total demand: 0.1 million vehicle)
Clustering

Network Clustering by Communication Network Design Method
Hub Selection

Hub Selection by Public Transport Area Method
Hierarchy Network Configuration

Network Hierarchy By Social Organization Area Method
Corridor Line Generation - Case 1

- Minimum Distance Rule
  - Set 2 corridor lines by Minimum Distance Rule
Corridor Line Generation Case 2

Maximal Flow Rule
- Set 4 corridor lines by Maximal Flow Rule
Corridor Line Generation Case 3

- Maximum Accessible Rule
  - Set 4 corridor lines by Maximum Accessible Rule
Minimum Travel Time Rule
- Set 4 corridor lines by Minimum Travel Time Rule
Application with MATSim
Procedure of MATSim

About MATSim
- Agent Based Model (activity-based demand)
- Dynamic Traffic Assignment (Route planning, iteration)
- Secondary Activities
- Large Scale Multi-agent Model
- Agent Based Model (Disaggregate)
  ⇒ analyze individual behavior through different trip chain
- Secondary activities (activity-based demand)
  ⇒ add origin and destination and secondary activities
- Dynamic Assignment (Iteration, Route choice)
  ⇒ see the route choice depending on the number of iteration
Building scenario

Flowchart of MATSim

- Network Data
- Facilities
- Plans
- Populations
- Demand

Execution

Scoring

Replanning

Analysis

BusanPlan.xml

- Home: Expectation areas of damage by tsunami
  Haeundea, Gwangalli: 0.1 million people, Gijang-gun: 0.05 million people. (Derived Demand is Based on statistics)
- Work: Safe Areas from tsunami
  Far from the river and sea
  High altitude area
- Transportation: CAR
**Simulation Conditions**

**Building scenario**

- **Network Data**
- **Facilities**
- **Population**
- **Demand**

**Plans**

**Execution**

**Scoring**

**Replanning**

**Analysis**

**Simulation Conditions**

- Iteration: 50 times
- Each iteration result: Set-up to create mvi file.
- Set-up time: 16:00
- Snapshot period: 5 min
- Make Module

```
<module name="planCalcScore">
  <param name="lateArrival" value="-18" />
  <param name="earlyDeparture" value="-9" />
  <param name="performing" value="+6" />
  <param name="traveling" value="-6" />
  <param name="waiting" value="0" />
  <param name="activityType_0" value="h" />
  <param name="activityTypicalDuration_0" value="12:00:00" />
  <param name="activityMinimalDuration_0" value="08:00:00" />
  <param name="activityType_1" value="w" />
  <param name="activityTypicalDuration_1" value="08:00:00" />
  <param name="activityMinimalDuration_1" value="06:00:00" />
  <param name="activityOpeningTime_1" value="07:00:00" />
  <param name="activityLatestStartTime_1" value="09:00:00" />
  <param name="activityClosingTime_1" value="18:00:00" />
</module>

<module name="strategy">
  <param name="maxAgentPlanMemorySize" value="5" />
  <param name="ModuleProbability_1" value="0.9" />
  <param name="Module_1" value="ChangeExpBeta" />
  <param name="ModuleProbability_2" value="0.1" />
  <param name="Module_2" value="ReRoute_Dijkstra" />
  <param name="ModuleProbability_3" value="0.1" />
  <param name="Module_3" value="TimeAllocationMutator" />
</module>
```
APPLICATION WITH MATSim

Visualizer Via
Evacuation Time_case 1

Case 1-1: corridor line by Minimum Distance Rule
  - Average trip duration: 06:50:30

Case 1-2: corridor line by Minimum Distance Rule (Considering contraflow)
  - Average trip duration: 03:30:30

<Evacuation Histogram>
Evacuation Time_case 2

Case 2−1 : corridor line of by Maximal Flow Rule
  - Average trip duration : 07:55:00

Case 2−2 : corridor line of Maximal Flow Rule (Considering contraflow)
  - Average trip duration : 05:05:30

<Evacuation Histogram>
Evacuation Time_case 3

- Case 3-1: corridor line of by Maximum Accessible Rule
  - Average trip duration: 06:50:30

- Case 3-2: corridor line by Maximum Accessible Rule (Considering contraflow)
  - Average trip duration: 03:30:00

<Evacuation Histogram>
**Evacuation Time_case 4**

- **Case 4-1**: corridor line of by Maximum Accessible Rule
  - Average trip duration: 07:55:30

- **Case 4-2**: corridor line by Maximum Accessible Rule (Considering contraflow)
  - Average trip duration: 05:15:30

![Evacuation Histogram](image-url)
Evacuation Time Summary

Evacuation time efficiency when Corridor line is set to contraflow
Case 3 takes the least time to evacuate

<table>
<thead>
<tr>
<th>Classification</th>
<th>Minimum Distance Rule</th>
<th>Maximal Flow Rule</th>
<th>Maximum Accessible Rule</th>
<th>Maximum Travel Time Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Contraflow</td>
<td>06:50:30</td>
<td>07:55:00</td>
<td>06:50:30</td>
<td>07:55:30</td>
</tr>
<tr>
<td>With Contraflow</td>
<td>03:30:30</td>
<td>05:05:30</td>
<td><strong>03:30:00</strong></td>
<td>05:15:30</td>
</tr>
</tbody>
</table>

<Evacuation Histogram>
A Guide to Highway Vulnerability Assessment

Purpose of this Guide

The Guide was developed as a tool for State DOTs to:

- Assess the vulnerabilities of physical assets such as bridges, tunnels, roadways, and inspection and traffic operation facilities, among others,
- Develop possible countermeasures to deter, detect, and delay the impact of threats to such assets,
- Estimate the capital and operating costs of such countermeasures, and
- Improve security operational planning for better protection against future acts of terrorism.

General Approach

- The six steps for conducting a vulnerability assessment of highway transportation

A Guide to Highway Vulnerability Assessment

Required Resources and Level of Commitment

- Asset data
  - National Bridge inventory System
  - Hazardous Materials information System
  - Threat data
- Law Enforcement
  - State’s Emergency Management Agency
  - Homeland Security Office
- Vulnerability data
- Consequence data
- Countermeasures data
- Cost data
- Policies, plans, and procedures
- Personnel (interviews)
- Geographic information systems (maps, drawings)
A Guide to Highway Vulnerability Assessment

Step – Consequence Assessment

- Plot critical asset criticality versus vulnerability

- In this step, criticality (X) and vulnerability (Y) coordinates are calculated for each asset.

\[ X = \text{Criticality} = (x/C_{max}) \times 100 \]
\[ Y = \text{Vulnerability} = (y/75) \times 100 \]

- Quadrant I identifies the assets with the highest criticality and vulnerability for implementing countermeasures.
Vulnerability and Criticality Assessment contrast to Tsunami

Vulnerability Assessment

- Define the Vulnerability and Criticality factors

<table>
<thead>
<tr>
<th>classification</th>
<th>Vulnerability Factor</th>
<th>Criticality Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>Distance(A)</td>
<td>Volume(C)</td>
</tr>
<tr>
<td>Definition</td>
<td>Travel distance on evacuation</td>
<td>Traffic flow on link using evacuation route</td>
</tr>
<tr>
<td></td>
<td>Travel time(B)</td>
<td>Accessibility(D)</td>
</tr>
<tr>
<td></td>
<td>Travel time to evacuation by corridor line</td>
<td>Total depth of node</td>
</tr>
</tbody>
</table>

Quadrant I: High Criticality, High Vulnerability
Quadrant II: High Criticality, Low Vulnerability
Quadrant III: Low Criticality, Low Vulnerability
Quadrant IV: Low Criticality, High Vulnerability

Plot the Vulnerability and Criticality Assessment (Evacuation Time_case 3)

The High priority section prepare to Tsunami
- Section 20, 23, 25, 27, 31, 35, 37, 39
Findings

- Development of Methodology of Hierarchical network design for evacuation route
  - Clustering by Communication network design Method,
  - Hub Selection by Public Transportation Area,
  - Network Hierarchy by Social Organization Area,
  - Corridor Line Generation by Public Transportation Area
    - Case 1: Minimum Distance Rule
    - Case 2: Maximal Flow Rule
    - Case 3: Maximum Accessible Rule
    - Case 4: Maximum Accessible Rule
- Result of MATSim simulation, Corridor Line set by Case 3 (Maximum Accessible Rule) is best
- People evacuated through the evacuation route (Corridor line by Maximum Accessible Rule) is required for 03:30:00 (including contraflow)
- We find some Vulnerability sections against Tsunami some by Vulnerability Assessment
Case Study on Seoul’s Hierarchical Bus Route Design
Seoul capital region overview

- **Population:** 24.4 million  
  (Seoul 10.5 million)  
  (49% of the whole country)

- **Number of registered vehicles:**  
  (Seoul 3.0 million)  
  7.8 million (45% of the whole country)

- **Area:** 11,791 km²  
  (Seoul 605km², Incheon 1,002km², Gyeonggi 10,184km²)  
  (Only 5.3% of the whole country)

- **Estimated number of daily car trips:** 18.2 million

- **Number of trips related with Seoul:**  
  8.2 million
Number of trips and mode share

Number of Trips

Mode Share

Year

Year
2004 Bus Reform: Background
Key Issues of Transport in Seoul before Bus Reform

Expansion of commuting area to Seoul
The traffic volume passing across the boundary of Seoul

Decrease of bus passengers
Number of passengers per bus per day
▷ 1,069 passengers (1983) → 504 passengers (2003)

Increase of traffic congestion
Average speed of cars in downtown
▷ 20.04 km/h (1994) → 16.3 km/h (2002)

Completion of subway network: 100 million US$/km investment
Consideration of Alternatives

- **Road Construction**: $30~80 million/km
- **Subway Construction**: $100 million/km
- **The Efficiency of Bus**: BRT (Bus Rapid Transit): $1.5 million/km

Optimum?
2004 Bus Reform: Implementation
Vision of Seoul Bus System Renovation

- Low cost • High efficiency city
  * 30 passenger car’s capacity = 1 bus
- Economize on energy
- Reducing air pollution

- Competitive public transport
  (Public transport > private vehicles)
  * speed
  * convenience
  * safety
  * social fair

World Best Transit City

“Seoul”

“75% by Transit”
Objective of Seoul Bus System Renovation

- **Previous Seoul Bus System**
  - Bus routes design according to bus companies interest
  - Slow, unscheduled bus
  - Poor service
  - Insolvent management

- **New Seoul Bus System**
  - Accessible bus
  - Convenient in connection & transfer
  - Timed bus service
  - Predictable in arrival time
  - Fast and convenient as subway
  - Friendly and safe bus
  - Approachable operation system
  - Pleasant and environment-friendly bus
  - Transparent and reliable bus management
  - Securing public interest
Bus Reform Structure

**New Operation System**
1) Trunk and Feeder Lines
2) New bus business scheme

**Support System**
3) Median exclusive bus lanes
4) Curbside bus lanes
5) Central Bus Management system
6) Transfer system
7) New transportation card
8) High quality buses
9) Distance-based fare system
10) Garages/bus stops renewal
11) Attracting passengers for subways
12) Passenger car management
13) Improving roads’ capability
14) Publicity
15) Internet Homepage

**Monitoring/Counter measures**
- BMS
- New transportation
- card system
- Speed analysis for buses/passenger cars
- Field investigation
- Customers’ reports/suggestions
- Periodical analysis → press release

**Bus Management Center**
16) TMC
17) Operation monitoring

**Further Task & Feed back**
Action Program: Better service for passengers

- Reorganized Route System
  - Functional Route system
  - Altered Bus colors
  - Trunk line, Feeder line, Circular, Wide-area
  - Reorganized route numbers

- New Fare System
  - Unified distance-based fare system
  - Free transfers
Reorganization of Bus Routes System

- **Trunk lines**: direct connection between the suburbs and downtown area, between the downtown areas

- **Feeder lines**: Linking to trunk line stops/subway stations for easy transfer, providing public transport for local demand
System Element: Transportation Card

Transportation Card
(Smart Card, etc)
- Distance-based Fare
- Free Charge for Transfers
2004 Bus Reform: Expansion
Expansion to Seoul Metropolis Area

- System Expansion:
  - July 2004: Seoul Buses and Subway
  - July 2007: Gyounggi buses
  - September 2008: Regional buses (178 routes, 2,499 buses)

- Fare structure:
  - Basic fare: 1,700KRW (within 30km) + 100KRW for additional 5km

- Expected saving: Maximum 0.5M KRW/year/passenger
Transportation Center

Yeoido Transportation Center

Seoul Station Center

Cheongnyangni Transportation Center, July. 2005
Bus Facilities: Exclusive median bus lanes and bus information system

• Exclusive median bus lanes of 100.4km are under operation

• Bus information system has been installed in 540 bus stops among 7,007 stops.
Information Provision Strategy for Dispersion

• Alternative Shortest Path Provision
• Space Syntax Technique
• Dynamic Shortest Path Calculation
• Short-term Travel Time Prediction
I. Alternative Shortest Path Finding using Space Syntax
II. Dynamic Shortest Path Algorithm
III. Discussion
Alternative Shortest Path Finding using Space Syntax
• Space syntax is the technique to analyze the connectivity of urban or architectural spaces.
• Has been applied to analyzing movement in indoor spaces or pedestrian paths (not in transport network).
• The study proposes a method to find an alternative shortest path using the space syntax technique.
• Movement can be described in an abstracted form using its topology.
• Topological description helps focus on the structural relationship among units.
  For example, pedestrian movement can be described using network of simple lines without considering the details such as sizes of forms, number of people and speed of movement.
• Topological description of streets network
Hierarchical structure of a street
Representing each component with a node and a turn with a link connecting their respective nodes

1. Step 1
2. Step 2
3. Step 3
• This relationship is described as a variable called *depth*. Depth of one node from another can be directly measured by counting the number of steps (or turns) between two nodes.
• Total Depth (TD)

TD_1 = 1 \times 2 + 2 \times 2 + 3 \times 1 = 9

\[ TD_i = \sum_{s=1}^{m} s \times N_s \]

TD_i: the total depth of node \( i \)

s: the step from node \( i \)

m: the maximum number of steps extended from node \( i \)

N_s: the number of nodes at step \( s \)
Alternative Shortest Path Finding using Space Syntax

Hierarchical Network Configuration

• Mean Depth (MD) = \( \frac{TD}{k-1} \)
• Normalized Depth (ND) \( \star \)

\( k \) : the total number of nodes

\[ MD = \frac{k-1}{k-1} = 1 \]

\[ MD = \frac{1 + 2 + \ldots + (k-1)}{k-1} = \frac{(k-1)k/2}{k-1} = \frac{k}{2} \]

\[ 1 \leq MD \leq \frac{k}{2} \]

\[ 0 \leq \frac{2(MD-1)}{k-2} \leq 1 \]
Alternative Shortest Path Finding using Space Syntax

- Apply of the Space Syntax theory
- Axial Map
- Find the axial line with highest space syntax value
- Transportation Data
- A* Boundary algorithm applies
- Shortest-Path Algorithm
- Deliver information
The difference of axial lines and transportation networks
Alternative Shortest Path Finding using Space Syntax

Space syntax Analysis

(a) Results using AXMAN method

(b) Results using the developed algorithm
### Searching methods

<table>
<thead>
<tr>
<th>Searching methods</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Whole searching</td>
<td>- The searching for path in whole field of links and nodes</td>
</tr>
<tr>
<td></td>
<td>- The most reliable method</td>
</tr>
<tr>
<td></td>
<td>- but, it takes long time to search</td>
</tr>
<tr>
<td>(2) Elliptic searching</td>
<td>- The searching for path in sphere of elliptic focused with origin and</td>
</tr>
<tr>
<td></td>
<td>destination</td>
</tr>
<tr>
<td></td>
<td>- It saves the time of searching</td>
</tr>
</tbody>
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**Explanation:**

- **Whole searching**
  - The searching for path in whole field of links and nodes.
  - The most reliable method.
  - But, it takes long time to search.

- **Elliptic searching**
  - The searching for path in sphere of elliptic focused with origin and destination.
  - It saves the time of searching.
A* Boundary algorithm applies
Highest Space Syntax Integration Value
Shortest-Path Algorithm Via Space Syntax
Alternative Shortest Path Finding using Space Syntax

<table>
<thead>
<tr>
<th>Paths</th>
<th>Distance (1)</th>
<th>Shortest Time (2)</th>
<th>Space Syntax (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6.10km</td>
<td>6.44km</td>
<td>6.20km</td>
</tr>
<tr>
<td>Distance</td>
<td>7 min 51 sec</td>
<td>7 min 14 sec</td>
<td>7 min 33 sec</td>
</tr>
</tbody>
</table>
Alternative Shortest Path Finding using Space Syntax

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</thead>
<tbody>
<tr>
<td>Distance</td>
<td>4.86km</td>
<td>5.30km</td>
<td>4.88km</td>
</tr>
<tr>
<td>Time</td>
<td>6 min 6 sec</td>
<td>3 min 58 sec</td>
<td>4 min 28 sec</td>
</tr>
</tbody>
</table>
Alternative Shortest Path Finding using Space Syntax

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<th>Space Syntax (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>18.95km</td>
<td>20.15km</td>
<td>20.72km</td>
</tr>
<tr>
<td>Time</td>
<td>22 min 50 sec</td>
<td>20 min 9 sec</td>
<td>25 min 25 sec</td>
</tr>
</tbody>
</table>
Alternative Shortest Path Finding using Space Syntax

<table>
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<tr>
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<th>Space Syntax (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.85km</td>
<td>5.01km</td>
<td>5.47km</td>
</tr>
<tr>
<td>Distance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>7 min 51 sec</td>
<td>5 min 14 sec</td>
<td>5 min 34 sec</td>
</tr>
</tbody>
</table>
Dynamic Shortest Path Algorithm
Short Term Prediction Techniques

- Multiple Regression Analysis
- ARIMA Technique
- Artificial Neural Networks Method
- Kalman Filtering Method
The Locations and Numbers of Image Processor Detectors

Numerical Analysis
Numerical Results

The Results of Prediction 15 Minutes ahead
Projection of short term prediction

- Difference problem happen prediction cycle and link travel time due to each link result travel time to prediction and predict a route travel time.
- The time interval of prediction time interval and present link travel time produced link travel time change by revision method.
Static Path & Dynamic Path Algorithms Analysis

- Dynamic Shortest path algorithm by predicted travel time use
Discussion

• Historical data and real time data Fusion Methods.

• Shortest Path Boundary Problem

• Real Time Application
Furniture Layout Design on Transit Stations

- Pedestrian Movement Modeling
- Different Layout Design for the Station Furniture
- Pedestrian Simulation on Designs
- Evaluation of Design
Introduction

Cellular Automata Pedestrian Model

Example of Applying CA Pedestrian Model

Comparison (Case Study) between CA model & Simwalk

Discussion
Background & Purpose

- The need for proper measurement of effectiveness of street furniture is demanding
- Analysis standard for various walking behavior is not yet established
- Diverse walking behaviors are depending on place, purpose and situation unlike vehicle
- Using Cellular Automata, quantitative analysis for pedestrian movement is now available
Flow of the research

Evaluation of Effectiveness in Various Furniture Layout

Development of Pedestrian Model

CA Model based on the Existing model

Apply that to the existing Model

Pedestrian Characteristics

Evaluating Pedestrian Furniture

Evaluation
Cellular Automata
Pedestrian Model
What is a Cellular Automata?

- Cellular Automata (CA) was first introduced by John von Neumann and Stanislaw Ulam in the late 1940s.

- Dynamics resulting from local interactions based on some rules can realistically emulate pedestrian movements.
Time-Space Structure of CA Model

- Continuous time-space is converted to discrete time-space
  - Space → divided into cell uniformized size
  - Time → divided into time step of uniform time interval

- The occupation status of unit cell is explained by binary system of computer (1,0)
- The integers are used to describe properties of an article, such as speed.

Article movement procedure
Algorithm for CA model

**Overall Algorithm**

Data input and initialization

Time = time + 1

Pedestrian generation

Pedestrian attraction

Lateral Movement

Front Movement

Time = Simulation time

End of simulation

**Generation and Attraction Algorithm**

Data of pedestrian volume for each time and direction

Probability of pedestrian generation in a cell for each second

Time = time + 1

Generation probability ≥ Random value

Accumulation of pedestrian in virtual link

Pedestrian exists in virtual link?

Search for attraction space

Attraction space exists?

Pedestrians of each class enter the attraction cell
Apply Characteristics of Pedestrian to Model

- **Front Movement Model**
  - Effective Spatial Evaluation
  - Regulation of Acceleration and Deceleration
  - Irregular Deceleration
  - Pedestrian Front Movement

- **Lateral Movement Model**
  - Compulsive path alteration of the pedestrians
  - Preference Route Change
  - Travel time Optimization of route Choice
4 Steps of Front Movement Model

- **Pedestrian Front movement Rule**: It moves to Front as Renewal Speed
  \[ x(t + 1) = x(t) + v(t + 1) \]

- **Irregular Deceleration**: Decrease or Increase speed by front gap
  \[ v(t + 1) = \min[v(t) + 1, v_{\text{max}}] \]
  or
  \[ v(t + 1) = \text{gap}_f(t) \]

- **Deceleration by probability per unit(1cell/sec)**
  \[ v(t + 1) = \max[v(t + 1) - 1, 0] \]

- **Valid gap Evaluation**: \[ \text{gap}_f(t) = v_{\text{max}} \]
  or \[ \text{gap}_f(t) = \text{gap}_f \]
  or \[ \text{gap}_f(t) = \text{gap}_f - 1 \]

- **Effective Spatial Evaluation**
3 Steps Of Lateral Movement Model

Pedestrian is not within a front recognition distance

\[ gap_f(t) \leq gap_i \quad \& \quad p_i \geq p_r \]

Pedestrian doesn’t walk for straight line

\[ gap_f(t) \leq gap_i \quad \& \quad p_m \geq p_r \]

If Probability condition: \( p_0 \geq p_r \)

If Probability condition: \( p_r \geq p_0 \)
Reflect Pedestrian’s characteristics

Conventional model:
Algorithm for side moving model

Suggested model:
Algorithm for lateral moving model

Only the left and the right sides are searched
When moving to the side

The diagonal cells are searched as well
when moving to the side
Example of Applying CA Pedestrian Model
Transfer stair Network for Simulation

- **Stair**
  - 3-dimensional crossing facility
  - Underground way, overhead bridge, terminal and subway station, etc.

- **General characteristic of pedestrian in transfer stair**
  - Bi-directional pedestrian group
  - Classified by the upward walking flow and the downward walking flow
  - Walking speed decreases in stair

- **Network for Simulation**

  ![Network Diagram]

  - Downwards
  - Upwards
  - 4.5m
  - 15m
Pedestrian behavior model in the transfer stair Fence design

**Establishment of Fence**

- Downwards
- Upwards

**Extension of Fence**

- Downwards
- Upwards

**Partial of Fence**

- Downwards
- Upwards

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pedestrian of flow (men/min/m)</th>
<th>Stair speed (m/min)</th>
<th>Fence (m/min)</th>
<th>extended (m/min)</th>
<th>partially (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(LOS A)</td>
<td>≤ 43</td>
<td>80</td>
<td>84</td>
<td>84</td>
<td>81</td>
</tr>
<tr>
<td>2(LOS B)</td>
<td>≤ 50</td>
<td>74</td>
<td>81</td>
<td>82</td>
<td>78</td>
</tr>
<tr>
<td>3(LOS C)</td>
<td>≤ 65</td>
<td>68</td>
<td>77</td>
<td>78</td>
<td>70</td>
</tr>
<tr>
<td>4(LOS D)</td>
<td>≤ 69</td>
<td>58</td>
<td>65</td>
<td>67</td>
<td>60</td>
</tr>
<tr>
<td>5(LOS F)</td>
<td>≤ 74</td>
<td>53</td>
<td>61</td>
<td>62</td>
<td>55</td>
</tr>
</tbody>
</table>

Fence is effective irrespective of types by dividing conflict movements.
Pedestrian behavior model in the transfer stair Fence location

Result of Fence location Scenarios

<table>
<thead>
<tr>
<th>LOS Scenarios</th>
<th>Pedestrian rate of flow (ped/min/m)</th>
<th>No fence case (m/min)</th>
<th>From Beginning to End case (m/min)</th>
<th>Downside Partially case (m/min)</th>
<th>Upside Partially case (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (LOS A)</td>
<td>&lt;43</td>
<td>Downwards 82</td>
<td>Downwards 88</td>
<td>Downwards 84</td>
<td>Downwards 82</td>
</tr>
<tr>
<td>2 (LOS B)</td>
<td>&lt;50</td>
<td>Downwards 75</td>
<td>Downwards 84</td>
<td>Downwards 79</td>
<td>Downwards 78</td>
</tr>
<tr>
<td>3 (LOS C)</td>
<td>&lt;65</td>
<td>Downwards 67</td>
<td>Downwards 77</td>
<td>Downwards 74</td>
<td>Downwards 73</td>
</tr>
<tr>
<td>4 (LOS D)</td>
<td>&lt;69</td>
<td>Downwards 60</td>
<td>Downwards 70</td>
<td>Downwards 64</td>
<td>Downwards 61</td>
</tr>
<tr>
<td>5 (LOS E)</td>
<td>&lt;74</td>
<td>Downwards 53</td>
<td>Downwards 65</td>
<td>Downwards 59</td>
<td>Downwards 56</td>
</tr>
</tbody>
</table>
Evaluation of Each Scenario by CA Model

1. Mark on sidewalk is set to reduce conflict between bus passengers. Conflict between pedestrians can affect pedestrian rate of flow and speed.

2. The bollard on the sidewalk can cause conflict between pedestrian and obstacle. Conflict caused by bollard can affect speed of pedestrian.

3. The width of sidewalk is 2.4m and it can affect capacity. And capacity of sidewalk affects pedestrian rate of flow, occupied space, density and speed.
Result of Case Studies by CA Model

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Rate of Flow (ped/min/m)</th>
<th>Speed (m/s)</th>
<th>LOS</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mark on Sidewalk at area of bus stop</td>
<td>Rate of Flow (ped/min/m)</td>
<td>Speed (m/s)</td>
<td>LOS</td>
<td>51</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.76</td>
<td>E</td>
<td></td>
<td>1.14</td>
</tr>
<tr>
<td>Reduce the Number of Bollard</td>
<td>Rate of Flow (ped/min/m)</td>
<td>Speed (m/s)</td>
<td>LOS</td>
<td>53</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.94</td>
<td>E</td>
<td></td>
<td>1.09</td>
</tr>
<tr>
<td>Expand Width of sidewalk</td>
<td>Rate of Flow (ped/min/m)</td>
<td>Speed (m/s)</td>
<td>LOS</td>
<td>49</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.17</td>
<td>D</td>
<td></td>
<td>1.22</td>
</tr>
</tbody>
</table>

Scenario 1: Mark on sidewalk at area of bus stop

conflict between pedestrians and passengers reduced and speed of pedestrian was increased

Scenario 2: Reduce the number of Bollard from 14 to 8

Reduce pedestrian’s behavior to avoid conflicts with bollard

Scenario 3: Expand width of sidewalk from 2.4m to 2.8m

Decrease the conflict between persons moving to each direction, and to increase their walking speed
Result of Case studies by Simwalk

Flow (ped/min/m), Speed (m/sec), Duration (sec)
Discussion
## Result of Simulation

<table>
<thead>
<tr>
<th>CA Model</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model has a flexibility to measure the effectiveness of pedestrian facility.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Front Movement Model</th>
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<tbody>
<tr>
<td>Pedestrian’ characteristics of front movement show group moving behavior</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lateral Movement Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian’ characteristics of lateral movement show diagonal overtaking behavior</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter Adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td>In order to realize real behavior, parameters are modified by adjustment range of each parameter</td>
</tr>
</tbody>
</table>

Supply levels and combination of facilities by performing the overall analysis of pedestrian facilities.

- Analyze the effectiveness of various facility.
- Evaluate each street furniture
Discussion

• Global warming leads natural disasters frequently and intensely.
• Transport planning methodologies are investigated if they can cover to accommodate disaster preventions and management.
• Transport planning should be extended towards more extreme cases.