On General Optimisation of a Stochastic Toll-Booth System Proposed in High Traffic Density Conditions

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Brief Contents

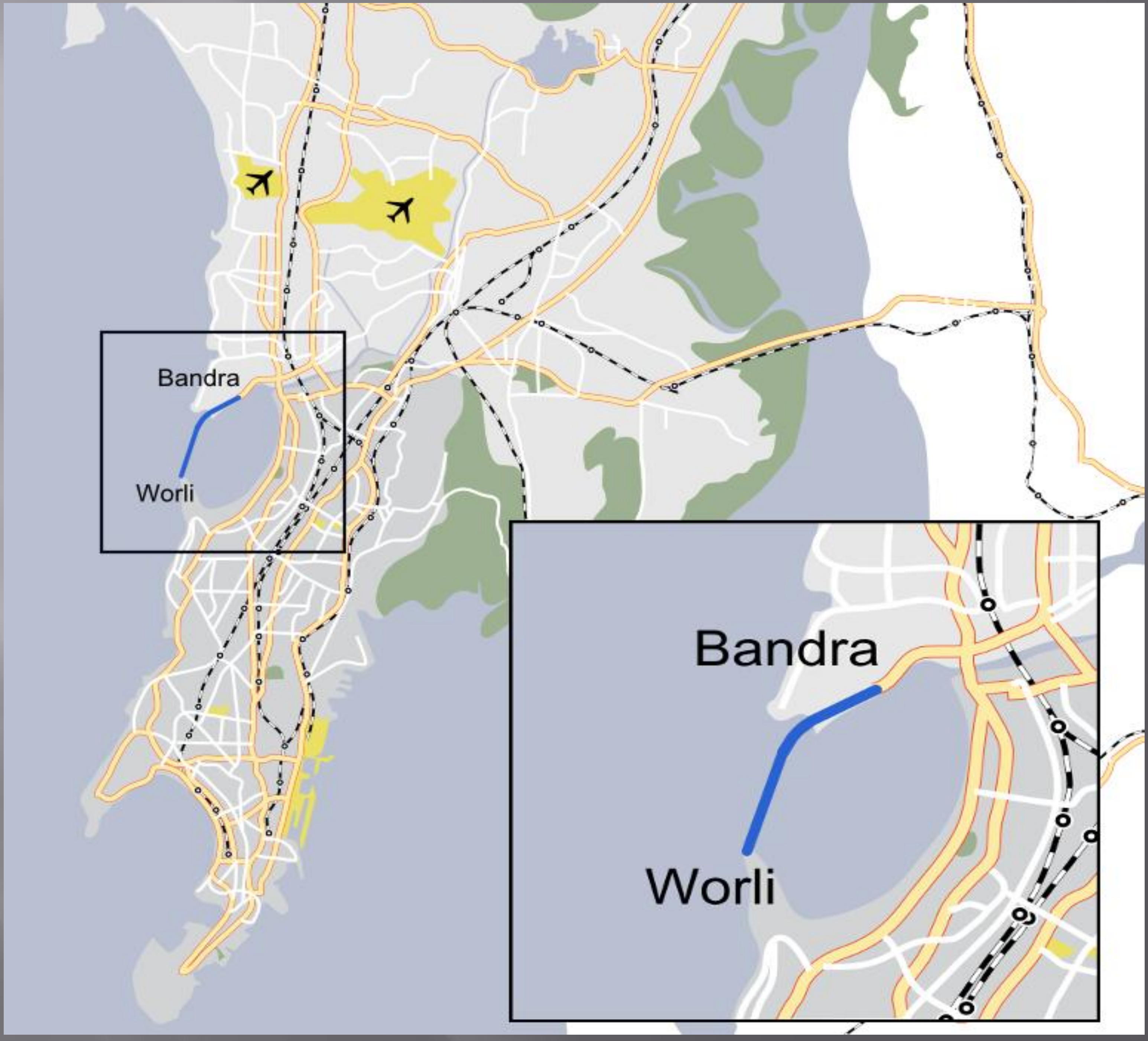
- Introduction- Toll Booth Systems and Stochasticity, Site of Study
- Methodology – Multi-phased
- Problem Formulation
- Results and Discussion

Introduction-Toll Booth Systems

- Randomised processes of arrival and serving
- Relation to Queueing Models
- High dissatisfaction levels among users found today

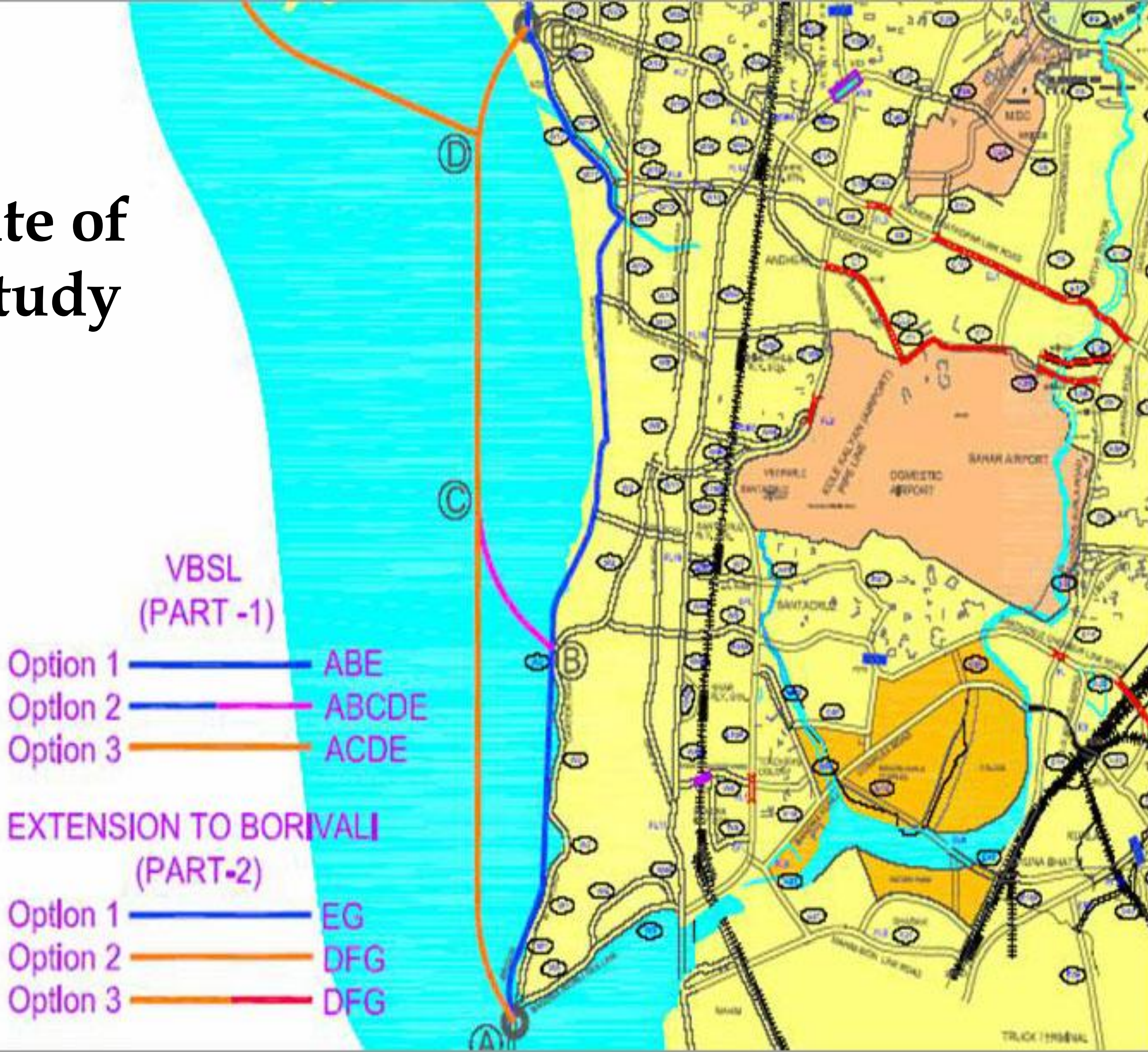
Site of Study

- The Versova –Bandra Sea – Link , Mumbai
- Proposed under MSRDC
- Connection with existing Bandra-Worli Sea Link
- Aim – Alleviation of suburban congestion on the parallel networks
- Connector-based entries



Bandra
Worli
Bandra
Worli

Site of Study



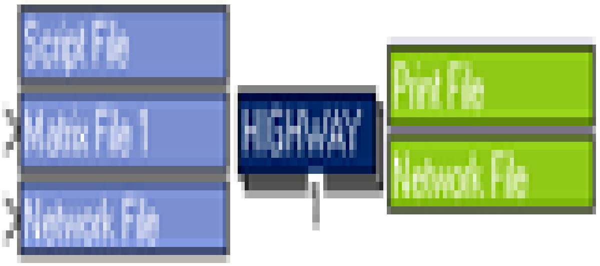
Methodology : Step 1

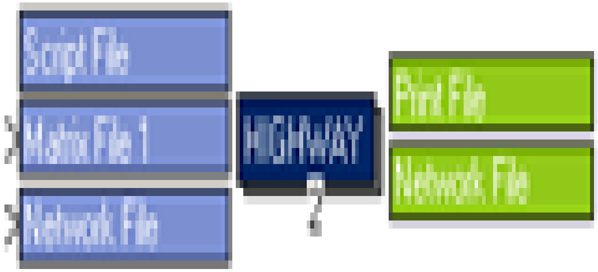
- Identification of the Queueing Model
- conventional process - M/M/1 models
- Not fully realistic in high traffic density conditions due to high variation of parameters from actual
- queue length and wait time get overestimated
- We use the M/G/1 model
- General Distribution of Service Times

Methodology : Step-2

- Traffic Assignment Modelling to Estimate the Expected Demand
- Lack of on-field volumes
- Cube 5.0 used for demand forecasting
- ‘HIGHWAY’ application used
- Input 1 - The network file of Mumbai region (completed with attributes of each existing network including counts, speed-delays, tolls)

‘HIGHWAY’ Application





Methodology : Step 3- M/G/1 Condition Parameters

- Assumption - Mean arrival rate per lane type is uniformly distributed across each lane
- (total number of lanes) N-large enough to efficiently process transactions

$$\sum_{i=1}^{K} n_i = \Lambda$$

M/G/1 parameters

- μ_i = *the mean service rate*
- λi = *the mean arrival rate*

$$\frac{\lambda_i}{n_i} < \mu_i \; \forall i$$

Condition to prevent bulking and avoid formation of infinite queues

M/G/1 parameters

- *L_i = the mean queue length, i.e., the mean number of vehicles waiting in the queue in type i lane*
- The Pollaczek–Khintchine (P-K) Formula for M/G/1 models –

$$L_i = \frac{\lambda_i^2(\mu_i^2\sigma_i^2+1)}{2n_i^2\mu_i\left(\mu_i-\frac{\lambda_i}{n_i}\right)}$$

σ_i = standard deviation of service time for a type i lane

- But, L_i not always a good criterion for performance comparison since services may differ over different lanes
- Mean waiting time in the queue impacts more
- Directly affects perception of service quality at the toll plaza by the motorists

- Hence, using Little's Law

$$W_i = \frac{L_i}{\frac{\lambda_i}{n_i}}$$

- *W_i = mean waiting time in queue for type i lane*
- *Then-*

$$W = \frac{\lambda(\mu^2\sigma^2 + 1)}{2n\mu\left(\mu - \frac{\lambda}{n}\right)}$$

Methodology : Step 4- Optimisation Scenario

- General toll operations involve two major costs – operating costs and user-waiting costs
- different magnitudes associated with peak and off-peak times
- aims of operation not be the same between peak and off-peak times.
- **Peak hours** - exploitation of plus-points more important than savings in operating costs
- Hence higher weights for user-waiting costs.
- **Off-peak hours** - congestion low
- Service standards well-satisfied even with partial capacity operation. Thus, higher weights are given to operating costs

Optimisation Scenario-Integer Programming

minimise

$$Z = \sum_{i=1}^{K} (c_i n_i + d L_i)$$

(c_i = rate of the operating cost of a type i lane
d = rate of the value of time to the driver waiting in queue)

subject to

1) $$\frac{\lambda_i}{n_i} < \mu_i \forall i$$

2) $$\sum_{i=1}^{K} n_i = N$$

(peak hours)

3) $\sum_{i=1}^{K} n_i \leq N$ (non peak hours)

4) $W = \frac{\lambda(\mu_i^2\sigma^2+1)}{2n\mu_i(\mu_i-\frac{\lambda}{n})}$

5) n_i = integer $\forall\ i$

Optimisation Formulation

- Objective function *Z* represents the sum of the total operating costs for all lanes used and the total user waiting costs incurred by all drivers in the queues per unit time

- To find the optimal lane configuration to minimize the total costs *Z* by satisfying the constraints.

Optimisation Solution

- Mumbai Scenario – no Automatic/Electronic Toll implemented before
- Hence solved for the manual lane scenario
- Waiting Time in queue = 40 sec
- Serving Time for Manual Server = 10-15 sec

Optimisation Solution

- Solution yields effective lane configuration
- Total six number of lanes required
- At some points, objective achieved, but service rate becomes less than arrival rate
- But at six, service rate satisfactory
- System remains stable with finite queues

Optimisation Solution

- Peak Hours - 08.00-11.00 hrs morning and 17.00-21.00 hrs evening in (Mumbai suburban scenario) – Full Capacity Operation Required

- Partial Capacity Operation also permitted

- Non-peak hours -(remaining times of day), two of the lanes maybe closed

- save manpower and operation-cost resources, without much affecting serving rates

Scope for Automated Tolling

- In principle, service improvement easily by providing additional booths
- In practise, space and cost restrictions disallow that

- Multiple Lane Configuration may hold the key
- Automatic Coin Machine (ACM) Lane, even the Electronic Toll Collection (ETC) to expedite the process.
- ETC is too expensive, the ACM can be implemented (enabled with currency note acceptance as high value coins are just beginning to be available in India)
- service rate much faster compared to manual (serving time of as low as 5-7 seconds due to the elimination of human factors)

Discussion

- configuration of (5,1)≡(Manual, ACM)
- a service improvement over the all-manual configuration
- Other benefit – encouragement to Mumbai drivers to start using it
- a positive step towards initiation of ETC lanes in future, like in USA, Germany
- Currently only one ETC-enabled system in India at Gurgaon

Discussion (..contd)

- Mumbai City desperately needs enhanced transportation solutions
- General driver- discontentment regarding transportation systems is growing each day
- Vehicle fleet growing each day
- This configuration (including automatic) first of its kind (even recent BWSL does not have)
- Possible future upgradation to ETC
- This work promotes LOS improvement right at planning stages of VBSL

Future Scope

- Feasibility evaluation of ETC-lanes for the VBSL

- Evaluating effective strategies to encourage current manual lane users to adopt automatic lanes

- Considering growth of traffic volume which may occur every year- working on a Dynamic Lane Configuration for it

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-RESP. PROFESSORS
- FELLOW STUDENTS
-ORGANISERS OF UMCSP, IIT MADRAS