A METHODOLOGY FOR SIMULTANEOUS BUS TRANSIT ROUTE NETWORK DESIGN AND FREQUENCY SETTING PROBLEM IN SMALL AND MEDIUM SIZED CITIES

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To my Father and Mother

Certificate

This is to certify that the thesis entitled, '**A methodology for simultaneous bus transit route network design and frequency setting problem in small and medium sized cities'** being submitted by **Mr. Seyed Mohammad Hassan Mahdavi Moghaddam** to the **Indian Institute of Technology Delhi**, is a record of the bona-fide research work carried out by him under our supervision. The thesis, in our opinion, is worthy of consideration for the award of the degree of **Doctor of Philosophy** in accordance with the regulations of the Institute. The results embodied in the thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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Abstract

The procedure of bus route network design that is a primary phase of public transit planning operation has a significant influence on the overall performance of operation. The design for bus passenger's movement in the real network is a complex non convex problem typically being NP-hard involving optimization of several parameters under some complex constraints. In reality, efficient procedure of utilizing the resources does not only depend on variations related to user's and operator's perspectives but also assessment of available infrastructure, analysis of input data, external effects of operation on the users and mathematical modelling. Hence, its efficiency and optimum performance depend on the way problem is explained. A proposed simultaneous bus route network design and frequency setting procedure is carried out in five phases. (1) The input analysis phase has the following sub-phases; (a) multiple objective function to minimize user, operator and pollution costs subject to constraints, (b) delineation of public transit traffic analysis zones and passenger travel demand matrix for bus stop level and (c) generation of operating network that has following sub-phases; (a) non-clustered operating network and (b) clustered operating network, (2) The generation phase has the following sub-phases; (a) path generation and filtration where different filtration rules are carried out to identify feasible regions within search space. Next, the performance, optimization and evaluation phases work all together in assessment procedure. (3) The route performance phase assesses generated candidate routes through the following sub-phases; (a) feasibility and connectivity check, (b) iterative passenger demand assignment procedure considering multipath effects. (4) The optimization phase generates initial solution from generated solution space and identifies an optimum set of routes with minimum total operations cost using genetic algorithm. A transfer minimization operator is implemented within genetic algorithm procedure to further increase the quality of solution and minimize the number of transfers and randomness of GA. (5) The evaluation phase works in-between the performance and the optimization phases. It evaluates optimum route sets according to related service frequencies (identified in performance phase). The proposed model is applied to small and large size test networks to investigate its efficiency and performance. Mandl's Swiss network is used as a benchmark network. Results confirm the efficiency of the proposed model through set of quality indicators. A bus transit network of Vishakhapatnam city as a small and medium sized Indian city is selected to further investigate the performance of proposed model for large size network. Results indicate improvement over the quality of operations compared to existing one on both clustered and non-clustered operating networks.

Keywords: simultaneous bus route network design, bus frequency setting, delineation of public transit traffic analysis zones, route generation, genetic algorithm, small and medium sized city, transfer minimization operator

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Abbreviations

AC	Access Time
APSRTC	Andhra Pradesh State Road Transport Corporation
ASAI	Actual Stop Accessibility Index
AON	All or Nothing Assignment
ATT	Average Travel Time
BRND	Bus Route Network Design
BRND-FS	Simultaneous Bus Route Network Design and Frequency Setting
BT	Bus Transit
EBT	Experienced Based Technique
EG	Egress Time
EPDA	Exhaustive Passenger Demand Assignment Procedure
ESM	Exhaustive Search Methods
GA	Genetic Algorithm
GIS	Geographic Information System
GS	Greedy Search Algorithm
GVMC	Greater Visakhapatnam Municipal Corporation
HC	Hill Climbing
HHS	Household Survey
ISAI	Ideal Stop Accessibility Index
IPT	Intermediate Public Transport
NP-Hard	Nondeterministic Polynomial-Time Hard
OD	Origin and Destination
RFA	Route Filtration Algorithm
RGA	Route Generation Algorithm
PS	Particle Swarm Algorithm
PT	Public Transit
PTTAZ	Public Transport Traffic Analysis Zoning
SA	Simulated Annealing
SCRI	Stop Coverage Ratio Index

SMC	Small and Medium Sized City
SPS	Stated Preference Survey
TAZ	Traffic Analysis Zones
TMO	Transfer Minimization Operator
TS	Tabu Search
UAC	Uniform Annual Cost
VOT	Value of Time

Notation

(i)	Origin bus stop (node)
(j)	Destination bus stop (node)

Demand

[$\mathrm{d}_{\mathrm{ij}}^{\mathrm{bus}}$]	Demand between origin and destination
[pd_{ij}^{bus}]	Potential demand between origin and destination
[pd_{ij}^{2w}]	2-wheeler potential demand to shift to bus for origin [i] and destination [j]
[pd_{ij}^{3w}]	3-wheeler potential demand to shift to bus for origin [i] and destination [j]
[$pd_{ij}^{bus\ to\ other}$]	Bus potential demand to shift to other modes for origin [i] and destination [j]
[pd_{ij}^{car}]	Car potential demand to shift to bus for origin [i] and destination [j]
[pd^{bus}]	Total potential demand
[D_{ij}^{bus}]	Total passenger demand between [i] and [j]
[$\mathrm{dtr}_{\mathrm{ij}}$]	Number of transfer passenger demand between origin and destination

TAZ delineation

$\left[A_{z'_{PTTAZ_m}}^{TAZ_n}\right]$	Trip attraction of proposed sub zone (PTTAZ) within particular TAZ
$\left[P_{z'_{PTTAZ_m}}^{TAZ_n}\right]$	Trip production of proposed sub zone (PTTAZ) within particular TAZ
[$\mathrm{d}_{\mathrm{i,j}}^{\mathrm{PTTAZ}_{TAZ_n}}$]	PTTAZ total demand including existing and potential demand belonging to n particular TAZ
[$\mathrm{pd}_{\mathrm{i,j}}^{\mathrm{pd,zone\ (n)}}$]	Potential demand between origin [i] and destination [j] of TAZ where [n] refers to zone
[$\mathrm{d}_{\mathrm{i,j}}^{\mathrm{ed,cell\ under\ netowork\ accessibility}}$]	

	PTTAZ existing demand under accessibility coverage that aggregated to cell grid
$[\mathrm{d}_{\mathrm{i,j}}^{\mathrm{pd,all\ cells\ of}\ TAZ_n}]$	PTTAZ potential demand under accessible and non-accessible area that aggregated to cell grid belonging to n particular TAZ
$[\mathrm{d}_{\mathrm{i,j}}^{\mathrm{zone\ (n)}}]$	Existing demand between origin [i] and destination [j] of TAZ where [n] refers to zone number
$[Z'_{PTTAZ}]$	Set of proposed PTTAZ (Cell grids)
$[Z_{TAZ}]$	Set of existing TAZ
$[z'_{PTTAZ_m}]$	Sub-zone of proposed PTTAZ where [m] refers to cell grid (sub-zone) number
$[z_{TAZ_n}]$	Sub-zone of existing TAZ where [n] refers to zone number
$[\delta_{z'_{PTTAZ_m}}^{A,B,C,D}\ \%]$	Population density ratio of each sub-section (A, B, C, and D) of cell grids (PTTAZ) where [m] refers to cell grid (sub-zone) number
$[\delta_{z'_{PTTAZ_m}}]$	Population density proportion of each cell grid PTTAZ

Cost

$[TOC]$	Total cost of operation
$[C_{user}]$	User cost
$[C_{Pollution}]$	Pollution cost
$[PC_{₹./km}^{Pollution}]$	Pollution cost factor in rupees per km
$[C_{Operator}]$	Operation cost
$[C_{operator}^{Running}]$	Running costs of operation
$[C_{operator}^{Fixed}]$	Fixed costs of operation
$[C_{operator}^{Maintenance}]$	Maintenance costs of operation
$[C_{bus-km}^{Deisel}]$	Bus running cost per km
$[Cost\ of\ Tires_{₹./km}]$	Cost of bus tires in rupees per km
$[Depreciation_{₹./km}]$	Fixed cost of bus depreciation in rupees per km

$[Driver\ cost_{₹./km}]$ Bus driver's salary in rupees per km

$[Fuel\ price\ _{₹.per\ litre}]$ Cost of bus fuel in rupees per liter

$[Motor\ vehicle\ taxes_{₹./km}]$ Motor vehicle tax as a part of operation cost in rupees per km

$[Personnel\ wages_{₹./km}]$ Salaries of operating personnel in rupees per km

$[Batteries\ and\ electrical_{₹./km}]$

Cost of bus batteries and electrical in rupees per km

$[Regional, Zonal\ and\ Head\ office\ charges_{₹./km}]$

Charges of operator's offices in rupees per km

$[Stores_{₹./km}]$ Bus operating store costs in rupees per km

$[Workshops_{₹./km}]$ Cost of bus workshops in rupees per km

$[Z_1]$ User related cost function

$[Z_2]$ Operator related cost function

$[Z_3]$ External pollution cost function

[W] Weighting rate for objective function

$[W_{externality}]$ External pollution cost related weightage in objective function

$[W_{operator}]$ Operator related weightage in objective function

$[W_{user}]$ User related weightage in objective function

Time

$[t_{ij}^{bus}]$ In-vehicle travel time

$[w_{ij}^{bus\ stop}]$ Waiting time

$[trp_{ij}^{Transfer}]$ Transfer time

$[ntrp]$ Transfer penalty

$[At_{passenger}^{bus\ stop}]$ Access time

$[Et_{passenger}^{bus\ stop}]$ Egress time

$[T_{total\ round\ trip\ Distance}^{bus}]$ Total round trip time by bus between origin and destination

$[T_{user}]$ Passenger total travel time

[VOT]	Value of time

Constraints

[$\mathrm{n}_{\mathrm{k}}^{\text{Max number of bus stop}}$]	Maximum allowable number of bus stops serving through route [k]
[$\mathrm{n}_{\mathrm{k}}^{\text{Min number of bus stop}}$]	Minimum allowable number of bus stops serving through route [k]
[$l_k^{Max\ number\ of\ links}$]	Maximum allowable number of links serving through route [k]
[$l_k^{Min\ number\ of\ links}$]	Minimum allowable number of links serving through route [k]
[$\mathrm{f}_{\mathrm{k}}^{\max}$]	Maximum allowable service frequency
[$\mathrm{f}_{\mathrm{k}}^{\min}$]	Minimum allowable service frequency
[$\mathrm{F}_{\text{max fleet size}}$]	Maximum allowable fleet size
[$\mathrm{RL}_{\mathrm{k}}^{\text{1st shortest path}}$]	Route length of first shortest path
[$\mathrm{RL}_{\mathrm{k}}^{\text{Max Route length}}$]	Maximum allowable route length
[$\mathrm{RL}_{\mathrm{k}}^{\text{Min Route length}}$]	Minimum allowable route length
[$\mathrm{trnp}_{\mathrm{ij}}^{\text{max Transfer}}$]	Maximum allowable number of transfers between origin [i] and destination [j]
[d_{un}]	Unsatisfied demand
[$\mathrm{F}_{\text{route k}}$]	Required fleet size on route [k]
[C]	Capacity of transit vehicles
[F]	Available fleet size
[α]	Load factor
[γ_k]	Route k that is below the minimum allowable number of bus stops

Network design and frequency setting

[$f_{\mathrm{k}}^{\text{route}}$]	Service frequency on route [k]
[$\mathrm{f}_{\text{route k}}^{off\ peak\ time}$]	Service frequency on route [k] in off peak time operation
[$\mathrm{f}_{\text{route k}}^{peak\ time}$]	Service frequency on route [k] in peak time operation
[f_{ij}]	Frequency between origin [i] and destination [j].

[f_{ji}]	Frequency between origin [*j*] and destination [*i*].
[$\mathrm{f_{ij}^{route\ k}}$]	Frequency between origin [*i*] and destination [*j*] of route [k]
[$\mathrm{q_{maximum\ load\ section}}$]	Maximum load section
[$\mathrm{trnp}_{\mathrm{ij}}^{route\ k}$]	Number of transfers between origin [*i*] and destination [*j*] of route [k]
[$\mathrm{trp_{ij,N,k}^{Transfer}}$]	Number of transfers imposed for origin [i] to destination [j] in candidate route [k]
[$RL_{\mathrm{k}}^{\mathrm{Route\ length}}$]	Route [k] length
[$R_{i,j,k}^{candidate}$]	Set of candidate routes [k] for all origin [*i*] and destination [*j*]
[$kSP^{directed\ graph}$]	Number of k shortest path for directed graph
[$kSP^{undirected\ graph}$]	Number of k shortest path for undirected graph
[$l_{\mathrm{k}}^{\mathrm{Route's\ number\ of\ links}}$]	Number of links serving through route [k]
[$wt_{tr}^{k,k'}$]	Waiting time at transfer point from route [k] and exchange to second route [k']
[γ]	Direct and indirect demand satisfaction ratio
[$\gamma^{direct\ ratio}$]	Direct passenger demand satisfaction ratio
[$\gamma^{indirect\ ratio}$]	Indirect passenger demand satisfaction ratio
[$n_{\mathrm{k}}^{\mathrm{Route's\ number\ of\ bus\ stops}}$]	Number of bus stops serving through route [k]
[RL]	Trip route length
[$\sum d$]	Total operation satisfied passenger demand

Genetic algorithm

[dv_i]	Substring [i] in genetic algorithm coding
[$\mathrm{n}_s^{\mathrm{k}}$]	Node [s] of particular [k] route of population [N] in genetic algorithm
[l_i]	Length of substring [i] in genetic algorithm coding
[$\gamma_{\mathrm{Nm}}^{indirect\ ratio}$]	Indirect passenger demand satisfaction ratio of population [N] with size [m] in genetic algorithm
[$\mathrm{N_m}$]	Initial random population in genetic algorithm where m is population size

$[N_m^k]$	Initial random population in genetic algorithm where k is number of individuals