Optimal placement of charging stations for Electric vehicles in Indian urban networks

Project Report

by

Yamini Sharma

Electrical engineering

NIT Hamirpur

Under the supervision of

Prof. Udit Bhatia

IIT Gandhinagar

Contents

List of Figures

List of Tables

Optimal placement of charging stations for Electric vehicles in Indian urban networks

October 15, 2021

Abstract

With increasing energy consumption, dependency on fossil fuels, increase in carbon footprints, a paradigm shift towards sustainable and viable options is necessary. As an effort towards greener technology, the inclusion of electric vehicles and electrification of transportation systems is being encouraged in various countries. The introduction of alternative vehicle technologies in the existing self-contained transportation system poses questions and challenges. Solely expanding the population of EVs in a city without enough road connections and corresponding charging and parking infrastructure will suppress the feasibility of EVs. Thus, supportive charging infrastructure is of utmost priority for large-scale adoption of EV systems. The charging station placement is a complex optimization problem involving power distribution network and road network and thus its solution must superpose the considerations of both the systems. Therefore, in order to find an optimal solution to this problem, multi-stage multi-objective solution approach is followed. Stage I aims at determining the candidate locations based on parameters like voltage stability factor, distance between nodes of traffic and distribution networks and congestion. Furthermore, in stage II optimization of the candidate locations based on cost of installations, penalties, range anxiety etc.is carried and off solutions are obtained. Initially, analysis is done on a 25-node transport network superposed on a 33-bus radial distribution network. Thereafter, the proposed model is applied to real urban network. (Chandigarh city)

1 Introduction

Siting and designing of EV charging stations requires an overlay of the urban networks on the power networks. Factors such as the charging capacity required, preference of users for mode of charging, and the total EV load depends upon various geographical, technical and transportation parameters. Appropriate siting and capacity determination of EV charging step is an important step to building a successful E mobility ecosystem. For appropriate location selection, considerations like heavy and slow traffic, commercial establishments, population density come into play. Thereby, a location specific analysis is essential to identify the needed charging capacity for a particular location. Further, prioritization of EV charging locations would depend on spare capacity in the Distribution Transformers (DTs) in the feeders connecting the charging stations, power sources and upgradation. Thus, it is essential to take these parameters when building a charging station. There have been significant amount of works solving the charging station siting and designing problem.

Compared to the existing works, the present work has following contributions:

• Two stage planning model has been laid for the optimal placement of EV charging station. In first stage, candidate locations are found followed by the optimization to get the best results. Furthermore, distribution network is analyzed to place the DGs effectively considering EV penetration.

• The charging station placement problem is modelled in the context of Indian urban city Chandigarh. The cities will be having large EV users, hence, there will be a necessity of sustainable charging infrastructure.

• This work focuses on placing the EV charging station taking into account both the traffic and electric grid parameters.

2 Problem Formulation

The charging station placement problem is a typical planning problem involving the interaction of both the transport and distribution networks. It is a multifaceted problem with a number of decision variables, objective functions and constraints. In the present work, the charging station placement problem is formulated as a multi-variable multi-objective, non-linear optimization problem. One of the salient features of the multi-objective formulation of this problem is inclusion of cost, penalty and waiting time as the objective functions. Brief of solution approach along with the objective functions and constraints is presented herewith.

2.1 Assumptions

- Urban setting
- Large EV penetration
- High utilization ratio
- Focus on FCS
- Sustainable solutions

2.2 Stage I: Determination of candidate locations for charging station placement

In the first stage, the potential locations for the placement of charging stations is determined using a probabilistic approach based on Bayesian network. It is often assumed that charging stations may be placed at the meeting points of distribution and road network, thereby making them the candidate locations. However, some of these nodes may have high traffic intensity while there is chance of some of these nodes being vulnerable points of the grid in terms of voltage stability, reliability etc. Therefore, here we consider distance of the road network nodes from the nearest bus of the distribution network, congestion and grid stability as the key factors for finding the candidate sites for placing the charging stations.

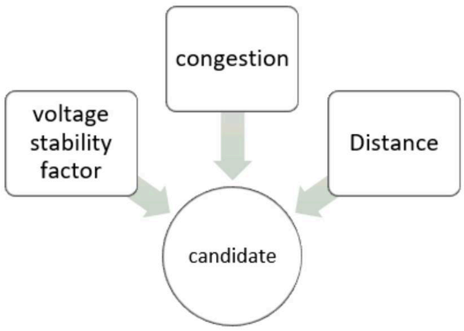

Figure 1: Bayesian net to determine candidate locations

The above Bayesian networks is used to find the candidate locations using VSF, congestion and distances.The following table explains the parameters and their respective states.

Parameter	Status
VSF	Low,medium,high
Congestion	Low,High
Distance	Low, Medium, High
Candidate	Yes, No

Table 1: Table of parameters for Bayesian net

Thereby, each bus being the candidate location is calculated using the formula:

$$P(candidate) = P(candidate|VSF, congest., distance) * P(VSF) * P(congestion) * P(distance) \tag{1}$$

2.2.1 Understanding Parameters

Voltage sensitivity factor (VSF):

It will help us to determine the weak and the strong buses of the distribution network. A high VSF value indicates that even for a small change in loading, there is a considerable voltage drop, thereby signifying weakness of the bus.
VSF is defined as the ratio of variation in voltage and variation in load and thus is mathematically defined as:

$$VSF = \left|\frac{\mathrm{d}V}{\mathrm{d}P}\right| \quad \forall P < P_{max} \tag{2}$$

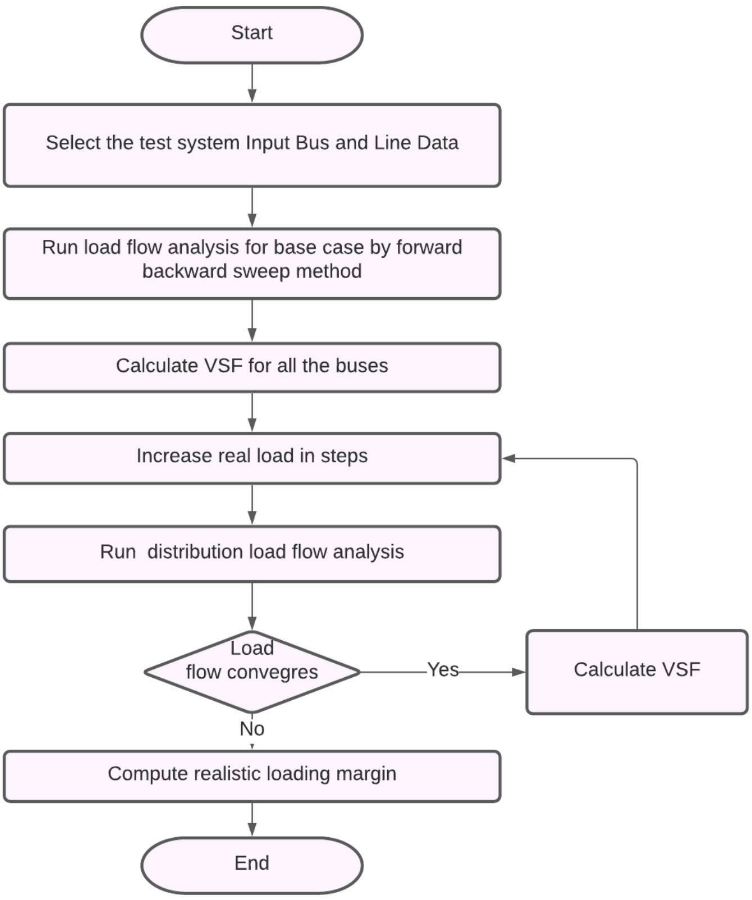

Figure 2: Algorithm to compute voltage sensitivity factor

Congestion probability:

A probabilistic approach based on Bayesian network is utilized to find the probability of congestion of the nodes of the road network. The probability of a road network being congested depends on the traffic flow which in turn depends on day of the week, time of the day, and area covered by the road.

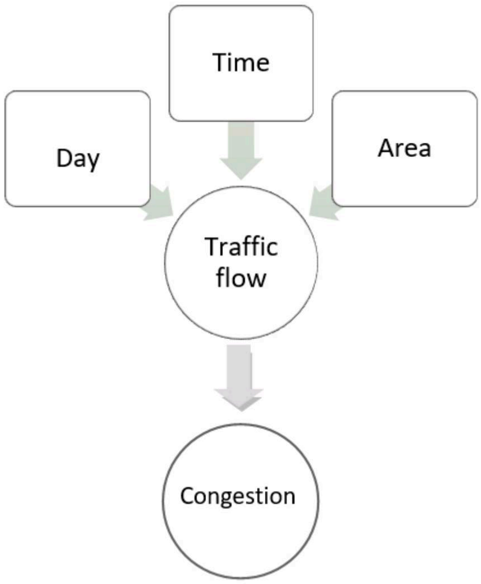

Figure 3: Bayesian net to determine candidate locations

Root node	States
Day	Weekday, weekend
Time	AM Peak, Work, PM Peak, Leisure, Rest
Area	Residential, Office , Market , School
Congestion	High, low

Table 2: Table of parameters for Bayesian net to determine congestion

The congestion probabilities were determined using the bucket elimination method.

2.3 Stage II : Optimization of candidate locations

The second stage of the proposed methodology involves finding the number of charging stations at the optimal locations. This is formulated as a multi-objective optimization problem with cost, penalties and waiting time at the charging stations as objective functions. Here is an overview of the multi-objective formulation with objective functions and constraints.

2.3.1 Objective functions

1. Cost
The objective function represents the gross investment cost of joint planning project (cost of installation and operation)

$$C_{installation} = \frac{r(1+r)^m}{(1+r)^m - 1} \sum_{i=1}^{n} (F_i \times C_{fast}) \tag{3}$$

$$C_{operation} = \frac{r(1+r)^m}{(1+r)^m - 1} \sum_{i=1}^{n} (F_i \times CP_{fast} \times P_{elec}) \tag{4}$$

$$Objective function \quad F_1 = \min\left(C_{installation} + C_{operation}\right) \tag{5}$$

2. Waiting Time

Under the premise of reasonable utilization rate of the charging station, the shorter the user's waiting time, the higher the customer satisfaction. The waiting time in the charging station is modeled by M/M/c queuing theory as follows:

$$W_f = \frac{\sum_{i=1}^{m} \frac{\rho_f^{f_i+1}}{(f_i-1)!\times(f_i-\rho_f)^2} \times P_0^f}{\lambda_f} \tag{6}$$

$$Objective function \quad F_2 = \min W_f \tag{7}$$

Constraint:

$$0 < F_i < F_{max} \tag{8}$$

This equation specifies the lower and upper bounds for no. of fast charging stations at one location.

Nomenclature

C_{fast}	Installation cost of fast charging stations
CP_{fast}	Power consumption of fast charging stations
P_{elec}	Per unit cost of electricity
n	Maximum number of locations in which charging station will be placed
Fmax	Maximum number of fast charging stations
λ_f	Arrival rate of EVs in fast charging stations (car/hr)
ρ_f	Utilization rate of fast charging stations
P_0^f	Probability of no. of EVs waiting in fast charging stations
r	Fixed rate of interest
m	Planning period

Table 3: Nomenclature

2.4 Stage III: Analysis of EV penetration and DG installations

The penetration rate of EVs in the future market can be influenced by different factors including the market price of EV, battery technology development, charging infrastructure, and government policy, etc. Market analysis and expert knowledge can be used to give a general estimation of the number of Electric Vehicle deployed at the end of the planning horizon. As the uncertainty from EV number can cause risk to the future charging system, it is essential to take the uncertainty of EVs' penetration rate into account while planning of sustainable infrastructure. The growth rate of EVs could be modelled by Gaussian distribution as follows:

$$p(\mu, \sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(X-\mu)^2}{2\sigma^2}} \tag{9}$$

The possible scenarios could be constructed based on statistical data, and the candidate planning could be applied into each scenario to find the optimal planning that could best compensate the difference in EV growth rates under each scenario.

Furthermore,DG installations could be incorporated based on this analysis.

3 Test System

The charging station placement problem is validated on the test network consisting of superimposition of 33 bus distribution network and 25 node transport network.

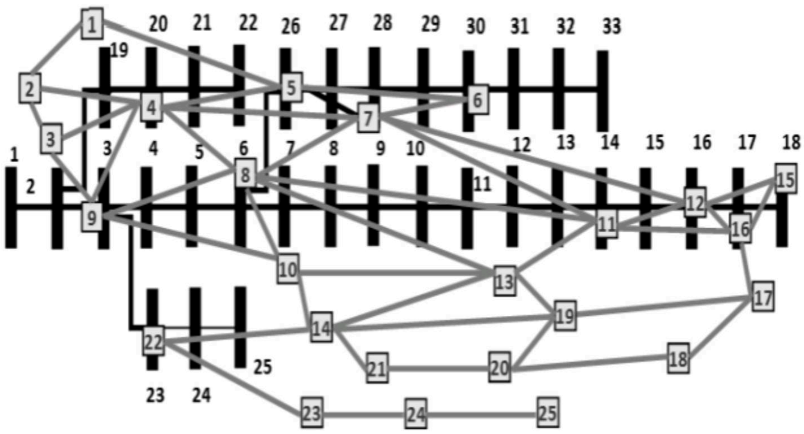

Figure 4: Test networks

Different types of nodes of the transport network are enlisted in the following table.

Type	Node No.
Residential	1,2,3,18,20,22,24,25,21
School	4,11,15,18,19
Market	13,14,16,17
Office	5,6,7,8,10,23

Table 4: Types of transport network nodes

Input parameters are numerated in the following table.

Parameter	Value
C_{fast}	\$3500
CP_{fast}	155 kW
P_{elec}	\$ 70/MWhr
λ_f	10 car/hr
ρ_f	0.75
P_0^f	0.85

Table 5: Input parameters

3.1 Stage I

On evaluation, the candidate locations(buses of distribution network) obtained are $P_{candidate} = (3, 5, 6, 7, 19, 22, 24)$

3.2 Stage II

Further, optimization results specify that the each candidate bus could have maximum of 4 charging stations. Therefore, based on the objective functions and constraints, buses 3,5,6,7,19,22 and 24 will be the locations for placement of charging stations and we could have maximum of 4 charging stations associated with each specified bus.

4 Case Study

To analyze the proposed system on a real network, Chandigarh city was considered for case study. Transport network for the same was obtained using Google maps API. Due to the lack of distribution network data, the distribution network of Chandigarh city has been modelled as ieee 69 bus radial distribution network.

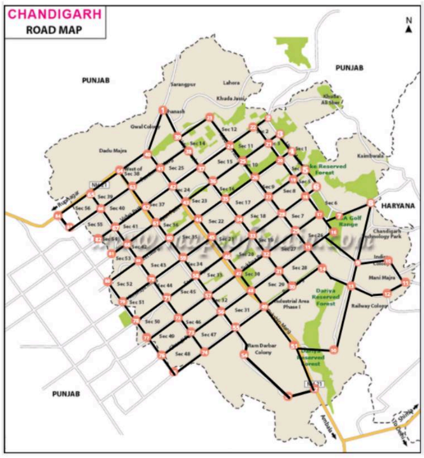

Figure 5: Road Map : Chandigarh

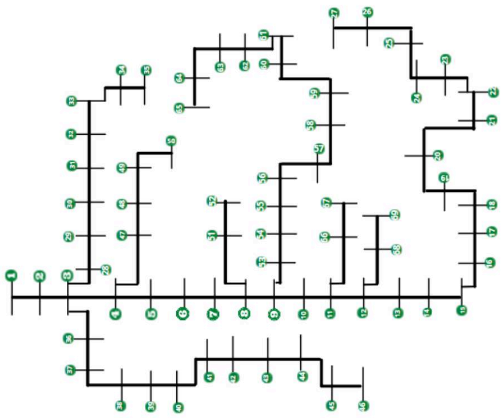

Figure 6: 69 bus Radial distribution network

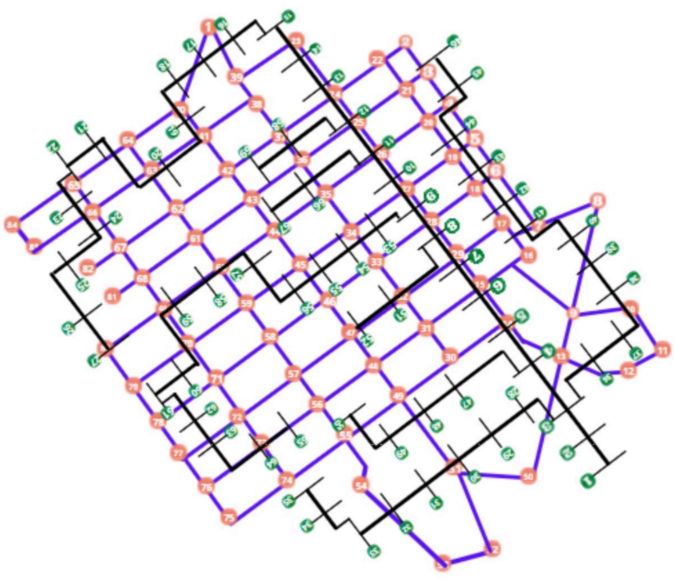

Figure 7: Superimposed networks

Figure 7 is the final network that was considered for the case study.

Different types of nodes of the transport network are enlisted in the following table.

Type	Node No.
Office	2,5,7,8,17,18,19,21,22,23,30,31,32,33,34,36,39,41,43,52,54,55,56,58,59,63,68,69,70,72,73,74,77,78,83,84
Residential	1,3,4,9,16,24,25,26,27,28,29,38,45,46,47,49,50,51,53,61,64,65,66,67,71,75,79
Market	6,12,14,15,20,37,40,42,48,76,82
School	10,11,13,35,44,57,60,62,80,81

Table 6: Types of transport network nodes

Input parameters are numerated in the following table.

Parameter	Value
C_{fast}	\$3500
CP_{fast}	155 kW
P_{elec}	\$ 70/MWhr
λ_f	25 car/hr
ρ_f	0.9
P_0^f	0.4182

Table 7: Input parameters

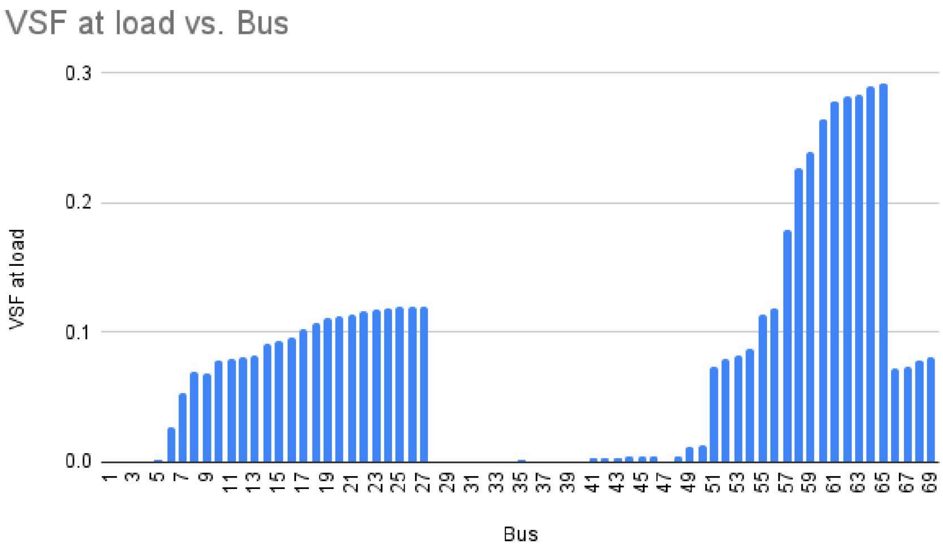

Figure 8: VSF vs bus

4.1 Stage I

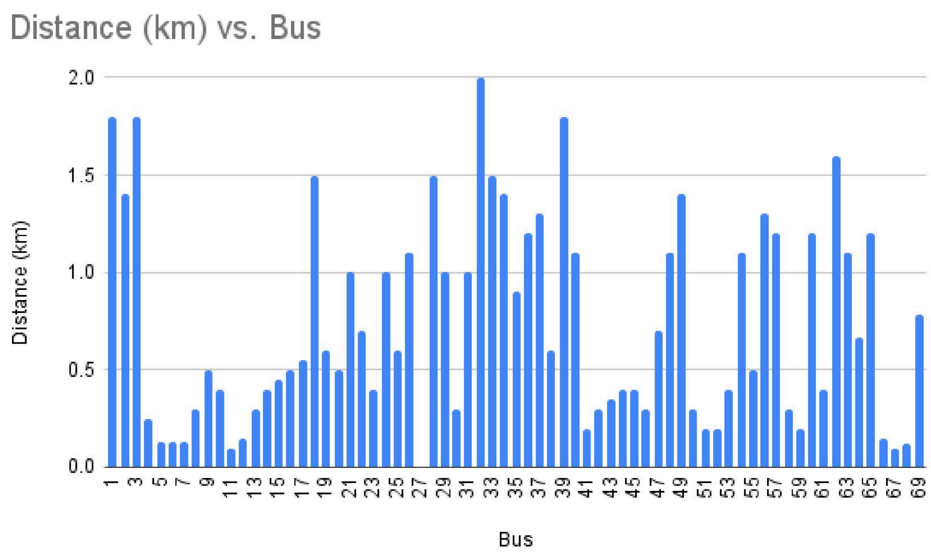

Figure 9: Distance vs bus

On evaluation, the candidate locations(buses of distribution network) obtained are $P_{candidate} = (1, 8, 10, 15, 17, 23, 25, 26, 27, 28, 29, 32, 34, 37, 42, 47, 55, 63, 65, 66)$

4.2 Stage II

Further, optimization results specify that the each candidate bus could have maximum of 4 charging stations. Therefore, based on the objective functions and constraints, buses 1, 8, 10, 15, 17, 23, 25, 26, 27, 28, 29, 32, 34, 37, 42, 47, 55, 63, 65 and 66 will be the locations for placement of charging stations and we could have maximum of 7 charging stations associated with each specified bus. Further analysis on the impact of EV penetration on the distribution network could be carried on and DGs could be installed.

5 Conclusion

In this research work, a multi-stage multi-objective joint planning model is developed for integrated EV charging system and distribution network planning. This research work develops a planning scheme integrated both the future charging facilities and renewable generation in power system planning. The installation of DG is beneficial to avoid both distribution line expansion and fossil fuel plant construction. The sites and sizes of DG could be properly planned to achieve the benefits from DG integration, such as loss reduction, peak load shaving, voltage drop control and investment deferral. This simultaneous optimal planning (placing and sizing) of EV charging system delivers a holistic solution for system planning. Therefore,we have established a sustainable and viable methodology to place the EV charging stations.
Also,this work solves the charging station placement problem in the context of Indian cities like Chandigarh. Future works in the same field might address some of the critical issues related to charging infrastructure planning like pricing strategies in the charging stations, planning of Vehicle to Grid (V2G) enabled charging stations,better renewable energy integration , stakeholders and maximum profits etc.

6 Results

This work has enabled us to locate the charging stations considering the aspects of both transportation and distribution networks and thus are feasible and optimal solutions.

7 Bibliography

References

[1] S. Deb, K. Tammi, K. Kalita, and P. Mahanta, “Review of recent trends in charging infrastructure planning for electric vehicles,” Wiley Interdiscipl. Rev., Energy Environ., vol. 7, no. 6, p. e306, 2018.

[2] S. Deb, K. Kalita, and P. Mahanta, “Review of impact of electric vehicle charging station on the power grid,” in Proc. Int. Conf. Technol. Advancements Power Energy (TAP Energy), Dec. 2017, pp. 1–6.

[3] S. Deb, K. Tammi, K. Kalita, and P. Mahanta, “Impact of electric vehicle charging station load on distribution network,” Energies, vol. 11, no. 1, p. 178, 2018.

[4] D. Ghosh, S. Deb, and D. K. Mohanta, “Reliability evaluation and enhancement of microgrid incorporating the effect of distributed generation,” in Handbook of Distributed Generation. Cham, Switzerland: Springer, 2017, pp. 685–730.

[5] M. M. Rahman, S. Barua, S. T. Zohora, K. Hasan, and T. Aziz, “Voltage sensitivity-based site selection for PHEV charging station in commercial distribution system,” in Proc. IEEE PES Asia–Pacific Power Energy Eng. Conf. (APPEEC), Dec. 2013, pp. 1–6

[6] S. Deb, K. Kalita, and P. Mahanta, “Impact of electric vehicle charging stations on reliability of distribution network,” in Proc. Int. Conf. Technol. Advancements Power Energy (TAP Energy) Dec. 2017, pp. 1–6.

[7] M. Mohammadi, F. Jolai, and H. Rostami, “An M/M/c queue model for hub covering location problem,” Math. Comput. Model., vol. 54, nos. 11–12, pp. 2623–2638, 2011.