Project Report

IE 501 Optimization Models

By

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Topic: Optimizing the Transportation System (E Buggy) in IIT Bombay Campus according to student academic hours

Problem Description: The current transportation system at the IIT Bombay campus consists of multiple modes of transport, including rickshaws and e-buggy vehicles. However, the system is not fully optimized to align with student academic hours. This causes a shortage of E buggies during peak hours and leads to inefficiencies and inconvenience for students. By aligning the system with student academic hours, we can improve accessibility and reduce travel time.

Approach: (The goal of the problem is to minimize the travel time of E buggies traveling on a route, which depends on the waiting time of students at their pick-up points and travel time from source to destination.)* The problem includes the development of the shortest route from student pick-up-points (Hostels) to destination (LHC), such that a minimum of two pick-up-points is covered in a route and no pick-up-point is visited by the E Buggies twice in one trip from source to destination (this would require multiple routes). The problem also consists of dealing with the scheduling and assignment of E buggies on multiple routes as needed during peak hours/academic hours.

To deal with the above problem we developed an Integer Linear Programming (ILP) **formulation** (link attached below) for this problem. The formulation consisted of various real-life constraints. We then developed a **Pyomo Modelling** (link attached below) as per the formulation and then used the GLPK solver to find the optimized routes.

Data:

Route 1:

Set of Hostels -{5,18,17,9,6,12}		Set of Buggies- {A,B,C,D,E,F}

Hostel	Waiting Time (min)	Travel time to LHC (min)	Min No. of Stops at hostel	Max no. of stops at hostel
H-5	2	4	4	6
H-18	1	7	2	4
H-17	3	8	3	5
H-9	2	8	5	5
H-6	1	9	5	7
H-12	1	11	2	4

Route 2:

Set of Hostels -{1,2,3,4}		Set of Buggies- {G,H,I,J,K}

Hostel	Waiting Time (min)	Travel time to LHC (min)	Min No. of Stops at hostel	Max no. of stops at hostel
H-1	2	4	4	7
H-2	1	7	2	5
H-3	3	8	3	6
H-4	2	10	3	8

Route 3:

Set of Hostels -{15,16}		Set of Buggies- {L,M,N}

Hostel	Waiting Time (min)	Travel time to LHC (min)	Min No. of Stops at hostel	Max no. of stops at hostel
H-15	2	8	2	6
H-16	1	9	3	5

1 Formulation

1.1 Symbols Definition:-

- $S \rightarrow$ Set of hostels
- $K \rightarrow$ Set of Buggies.
- $t_i^{trav} \rightarrow$ Travel time from LHC(Lecture hall) to hostel i .
- $t_i^{wait} \rightarrow$ Waiting time at hostel i
- $R_i^{min} \rightarrow$ Minimum number of buggies that must stop at hostel i
- $R_i^{max} \rightarrow$ Maximum number of buggies that must stop at hostel i
- $M \rightarrow$ A sufficiently large number.

1.2 Decision Variable

- $x_{ki} = \begin{cases} 1 & \text{if buggy } k \text{ stop at hostel } i \\ 0 & \text{otherwise} \end{cases}$
- T_k : Time taken for the k^{th} buggy for one journey

$$T_k = \sum \left(x_{ki}.t_i^{\text{wait}}\right) + 2 \max_{i \in S} \left(x_{ki}.t_i^{trav}\right)$$

- C_k : Variable for constructing $\max_{i \in S} \left(x_{ki}.t_i^{\text{trav}}\right)$

$$b_{ki} = \begin{cases} 1, & \text{if } x_{k_i} \cdot t_i^{\text{trav}} \text{ is the largest} \quad \forall i \\ 0 & \text{otherwise} \end{cases}$$

1.3 Constraints

1. Satisfies the minimum no of buggy

$$\sum_{k \in K} X_{ki} \geqslant R_i^{\min} \quad \forall i \in S$$

2. Satisfies the maximum no of buggy

$$\sum_{k \in K} x_{ki} < R_i^{\max} \quad \forall i \in S$$

3. Modelling the max function

$$C_k \geqslant x_{ki} \cdot t_i^{\text{trav}} \quad \forall i, \forall k$$

$$C_k \leqslant x_{ki} \cdot t_i^{\text{trav}} + (1 - b_{ki}) .M \quad \forall i, \forall k$$

$$\sum_{i \in S} b_{ki} = 1 \quad \forall k \in K$$

4. Each buggy must stop at least one hostel .

$$\sum_{i \in S} x_{ki} \geqslant 1 \quad \forall k \in k$$

1.4 Objective function:-

Minimize the average journey time for each buggy

$$Minimize : \frac{1}{K}\sum_{k\in K} T_k$$

Results:

```
Route 1:

Objective value(Average time taken for each buggy journey): 23.666666666666664
Buggy assignment:
Buggy A :
LHC ----> Hostel 5 ----> Hostel 17 ----> Hostel 9 ----> Hostel 6 ----> LHC
Time Taken: 26.0
Buggy B :
LHC ----> Hostel 5 ----> Hostel 17 ----> Hostel 9 ----> Hostel 6 ----> LHC
Time Taken: 26.0
Buggy C :
LHC ----> Hostel 9 ----> Hostel 6 ----> Hostel 12 ----> LHC
Time Taken: 26.0
Buggy D :
LHC ----> Hostel 5 ----> Hostel 18 ----> Hostel 17 ----> Hostel 9 ----> Hostel 6 ----> LHC
Time Taken: 27.0
Buggy E :
LHC ----> Hostel 5 ----> LHC
Time Taken: 10.0
Buggy F :
LHC ----> Hostel 18 ----> Hostel 9 ----> Hostel 6 ----> Hostel 12 ----> LHC
Time Taken: 27.0
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Route 2:

Objective value(Average time taken for each buggy journey): 20.200000000000003
Buggy assignment:
Buggy G :
LHC ----> Hostel 1 ----> LHC
Time Taken: 10.0
Buggy H :
LHC ----> Hostel 1 ----> LHC
Time Taken: 10.0
Buggy I :
LHC ----> Hostel 2 ----> Hostel 3 ----> Hostel 4 ----> LHC
Time Taken: 26.0
Buggy J :
LHC ----> Hostel 1 ----> Hostel 3 ----> Hostel 4 ----> LHC
Time Taken: 27.0
Buggy K :
LHC ----> Hostel 1 ----> Hostel 2 ----> Hostel 3 ----> Hostel 4 ----> LHC
Time Taken: 28.0
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Route 3:

Objective value(Average time taken for each buggy journey): 20.333333333333332
Buggy assignment:
Buggy L :
LHC ----> Hostel 15 ----> Hostel 16 ----> LHC
Time Taken: 21.0
Buggy M :
LHC ----> Hostel 15 ----> Hostel 16 ----> LHC
Time Taken: 21.0
Buggy N :
LHC ----> Hostel 16 ----> LHC
Time Taken: 19.0
```

- The results display the sequence of hostels visited by the Buggies which are divided among 3 routes (which keeps on changing as the data changes) and the total travel time between source to destination (which keeps on changing as the data changes).

- If a buggy decides to go to a hostel that takes more time than others then it will surely go to hostels that take less time than it because routes are defined in such a way that they occur in one line.

- Hostel 4 refers to Tansa House which is on route 2 after hostel 3.

- The minimum and maximum no. of visits to a hostel is designed to accommodate the student demand at each hostel.

- A particular waiting time for each hostel is defined such that students get enough time to catch the buggy according to the student demand of each hostel.

- The above result approximates the optimal routes to be followed by the buggies considering the usual demand at the hostels. This same formulation can be used to simulate the transportation routes during exams and special days where the student demand at each hostel changes. The waiting time at each hostel and the maximum and minimum number of visits to each hostel have to be modeled accordingly.

Important Links:
Formulation:
https://drive.google.com/file/d/16zCdW24NI3I0no8KZ2Dl8aBCtRzmVESc/view?usp=sharing

Pyomo Modelling:
https://drive.google.com/file/d/15chy3KEYBGaA6W_XYN-qGI5tru3Pxaiq/view?usp=drive_link

Presentation Slides:
https://docs.google.com/presentation/d/1Ve7Kvcl0dPqt6tebuycORHVzDRLeF9TUH5e6cA-1QNk/edit?usp=sharing

References Used:

- Manumbu, D. M., Mujuni, E., & Kuznetsov, D. Mathematical Formulation Model for a School Bus Routing Problem with Small Instance Data. Mathematical Theory and Modeling, ISSN 2224-5804. Retrieved from http://www.iiste.org/
- Zeng, L., Chopra, S., & Smilowitz, K. (Year). A Bounded Formulation for The School Bus Scheduling Problem. ArXiv, https://doi.org/10.48550/arXiv.1803.09040
- Jianguo Qi, Valentina Cacchiani, Lixing Yang, Chuntian Zhang, Zhen Di An Integer Linear Programming model for integrated train stop planning and timetabling with time-dependent passenger demand. https://www.sciencedirect.com/science/article/pii/S0305054821002318#d1e5971
- K. Gkiotsalitis a, C. Iliopoulou b, K. Kepaptsoglou. An exact approach for the multi-depot electric bus scheduling problem with time windows. https://doi.org/10.1016/j.ejor.2022.07.017

Conclusion:
In conclusion, optimizing the transportation system at the IIT Bombay campus to align with student academic hours is crucial for enhancing efficiency. By analyzing data and improving routes we can create a student-centric transportation experience. The benefits include reduced waiting time and a more productive academic environment.