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Traffic Control in a Smart Intersection by an Algorithm with Social Priorities

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Abstract

This research deals with the case of a smart intersection, where several cars approach the intersection from various directions, and a smart traffic light must decide about the time intervals of RED and GREEN in each direction, based not only on the number of vehicles in each lane, but also on other factors such as the type of vehicles (e.g. emergency vehicles), and the social characteristics of the passengers (e.g. a handicapped person, a student who is late for an exam). Those factors will be gleaned from the IoT (Internet of Things) network amongst cars, traffic lights, individuals, municipality data, and more. Once those priorities have been examined, they are fed into the algorithm we have devised, and outputted as a timing schedule for the different sides of the intersection. In this paper we present the algorithm, the prioritizing research, its implementation in the algorithm and initial results.

Keywords: Smart Junction, Internet of Things, Social Dilemmas of IoT, Transportation Optimization Algorithms

1 Introduction

The Internet of Thing (IoT) is been called the next industrial revolution. This technology transforms our environment to be smart by providing the surrounding objects with the ability to collect data, analyse it and make decisions.

This technology uses large databases, data analysis capabilities (including the use of artificial intelligence) and various electronic sensors serving as end units embedded in different machines. Each end unit can collect information from the environment and transmit it to a central data base [cloud]. The information undergoes immediate analysis using relevant algorithms, and a decision on the type and method of execution is transmitted back to actuate a specific automatic action by the end unit ([13]).

A smart junction is an IoT implementation. In the past decade there have been several developments in the field of smart junction traffic lights for better management of traffic load, reducing drivers' frustration and loss of man hours. One of the first papers published in the field of smart junctions ([9]) introduced an elaborate algorithm for traffic-light time-handling which was applied for several vehicles at a single junction with several lanes and roads. A database was used for the management scheme, and the simulation showed that the dynamic adjustment algorithm could even handle some extreme cases, such as different emergency scenarios. The emulation of the system showed that the algorithm could navigate the traffic efficiently, and adjust itself to various cases of transportation incidents.

The basic division of movement in a junction is undertaken by separating the lanes into sides of conflicts, whilst the meaning of a lane being on the same conflict side as another one is that they can both move simultaneously. The timing of green lights is implemented by a negotiation of these conflict sides.

Since then, several researches, such as [5], [10] and [6], were published, improving the algorithm by adding factors and extreme cases to it, simulating real-time traffic cases, and calculating timing rates; several different levels of traffic intensity were considered to test the effectiveness of the proposed approach. The improved algorithms include calculation of traffic light sensor response, and, for the disruption status for extreme cases (such as an ambulance), fingerprints-based embedded authentication systems have been implemented as a self-contained sensor to increase the security of the system.

In [10] a new algorithm was devised to determine green times and the phase sequence of traffic lights, based on measured values of traffic flows, which shortened waiting times for most vehicles in the lane queue. This research was the first significant one that transferred the theoretical idea of a smart junction to a more applicable one, in which the technology of wireless sensor networks was used to manage the time handling by traffic load criteria.

Another improvement was suggested in [6] considering and evaluating drivers' behaviours (in this paper, specifically in Italy), such as crossing a junction in a yellow light when the waiting time is long, and considering the geometry of the junction, i.e.: visibility triangles, blind spots, the presence of constructions, and other factors causing the drivers to make various manoeuvres.

A very recent development is presented in [12], where the authors suggest a highly efficient algorithm that handles real-time traffic in a junction and, for the first time, takes into consideration highly-extreme cases and scenarios. In these scenarios, multiple emergency vehicles approach the signalized junction, and the algorithm tries to handle the traffic and prevent life-threatening cases, like the crossing of an emergency vehicle in a red light, while there is opposite traffic passing on its green light, by always giving the emergency vehicle priority over all other vehicles when proceeding through any signalized road intersection.

Better junction traffic load management can reduce accidents caused by the Red Light Running (RLR) phenomenon ([6]). This is a behavioural phenomenon that occurs when the driver chooses to cross (or not) the road when the traffic light changes from green to yellow. When the driver is stressed from excessive waiting times in the queue, bad decisions are taken and accidents occur. Reducing the waiting times in the queue, can reduce the accidents rate.

The idea that stress has an impact on decision making is supported by the decision-making literature which shows that in an uncertain stressed environment, intuitive and emotional processes are involved, instead of rational ones ([1], [11]). Knowing the correct decision would induce better behaviour. Elements of moral power (the impact of potential damage vs. potential benefits) and social consent should be taken into consideration in the decision making process ([8]).

Moral decisions are investigated within the framework of autonomous vehicles (AV) and accidents in [2]. The research found that drivers approved of utilitarian AVs (that is, AVs that would be prepared to sacrifice their passengers' interest for the greater good) and would like others to buy them, despite the fact that they would themselves would prefer to ride in AVs that protect their passengers at all costs. The conclusion of this research was that regulating for utilitarian algorithms may paradoxically increase casualties by postponing the adoption of a globally safer technology.

This article argues that adding a social preference parameter to the junction traffic management algorithm can reduce driver stress, by making traffic congestion at the intersection seem more just, thus reducing the accident rates. Examples of such a social preference parameter would be higher priority for a school bus or a car with a woman in labour.

In addition, we argue that adding a social preference parameter to the junction traffic management algorithm can promote the adoption of smart junction technology, thus reducing the accident rate. However, the smart junction is part of IoT (Internet of thing) technology, which is considered to be a disruptive innovation and, as such, has the potential to delay the adoption process ([4]). For instance, the Gartner study shows that IoT technologies in smart cities are still at the Technology Trigger stage ([3]). According to the technology acceptance model (TAM), which is a theory that models how users come to accept and use new technology, the adoption process of a new technology is influenced by the direct and indirect intentions of users, based on social influence, on the actual use of technology, and on the perceived usefulness of the system ([7]).

We note that another benefit accrued from adding a social preference parameter to the junction traffic management algorithm, is helping municipalities to promote a car sharing scheme for reducing traffic load.

2 Methods

In this research, we have devised a smart junction algorithm that includes social priorities. The manifestation of the algorithm is in a web-based software simulator that was built for the purpose of this research.

2.1 The web-based software simulator algorithm

The system gives the user the option of submitting numerous attributes for the vehicle queues at a given junction. An attribute unique to this research and algorithm is a social priority attribute for every vehicle (such as the priority evaluation of a person late for work, or for a person late for a doctor's appointment, etc.), and a summation of all of these vehicle priorities in a given queue. Special interrupting priorities are given to emergency vehicles or emergency cases (such as a vehicle carrying a woman in labour on her way to the hospital) in the algorithm and the simulator.

After submitting the description and number of vehicles and priorities in the queues of the junction, the user receives an efficient and fair-fitting traffic light timing schedule that will reflect the most appropriate scheme of traffic in a given amount of time.

We take several things into consideration in this algorithm: first of all, the number of people in a vehicle and the size of the vehicle do not matter at this point (future directions may be to include analysis of these attributes as well). Second, the given junction includes all possible directions of queues. If a certain direction does not exist (like in a T-junction), the algorithm trivially takes this side as a zero priority, which is the same as it would have taken for an empty queue; thus, it does not influence the effectiveness of the algorithm. Third, when an emergency vehicle is in one of the queues, this queue gets the first time slice until this vehicle passes the junction, and then the rest of the queues get their time slices. The algorithm relates to a snapshot of given vehicles at a junction, and calculates the scheduling from this snapshot. Of course, there could be a case of an emergency vehicle that arrives during the scheduling; for that case, there could be a "back-door" of stopping the algorithm, and, thus, the traffic, and giving the emergency vehicle its needed time. Fourth, in the algorithm's description we refer to the term "conflict side", which is defined as follows: a conflict side is all of the lanes (directions) in a traffic junction that can move simultaneously. Fifth, the major advantage of this algorithm is that it takes into consideration both traffic loads and social priorities, which is distinct from other traffic light algorithms.

The general description of the algorithm is as follows:

- Insert the number of queues and the number of vehicles in each queue.
- Insert the conflicts of the junction (which roads intersect, and thus cannot have simultaneous green lights).
- Insert special interrupting priority vehicles, if such exist. The special interrupting priorities are chosen and approved only by the municipal authority, and are transmitted automatically to the traffic light sensor by the emergency vehicle itself.

- For every vehicle, insert a priority from a given set of cases, formulated as numerical values. The insertion of the priorities is done by a designated application in the vehicle's system or in the driver's cell-phone. This kind of application is commensurate with current technology, and will be further facilitated with the ongoing developments of IoT in vehicles.
- For every vehicle queue, sum the numerical values of the priorities.
- For every junction conflict side (the queues that can drive simultaneously) sum the joint priority value.
- Evaluate the green-light time for each conflict side relative to the attribute of the joint priority value.
- Time the green-light duration of each side, beginning with the interrupting priority vehicles, and then by the evaluation done for the junction conflict sides.

2.2 The Social Preference Questionnaire Description

A Social Preference Questionnaire was designed for receiving vehicle priorities at a smart junction. The questionnaire included multiple-choice questions; each question contained a choice between values on a scale of 1 to 10. Vehicles were divided into categories. The vehicle types and categories are presented in table 1. The research participant was asked to select a priority for crossing the junction per each vehicle type. The questionnaire was conducted electronically via a Google Form. 230 research participants were divided into 2 groups. 144 participants were first degree students studying in MLA College. The other group was composed of friends and family of the researchers. Figure 1 presents the research participants' distribution by gender and age. The gender was composed of 64% men and 36% woman. The age range of the participants was from 18 to 50+.

2.3 The web-based software simulator algorithm

For a given junction with traffic lights, and a priority attribute for every car in the junction, we defined the algorithm given in Algorithm 1.

Table 1. Questionnaire vehicles by category and type

Category	**Vehicle Type**
Rescue vehicles	Such as ambulance, police, firefighting
Public Transport	Bus Service taxi Private taxi Uber
Emergency	Car with a woman in labor Car with a seriously injured passenger Car with a moderately injured passenger
Number of passengers in vehicle	Private car with at least 4 people Minibus with at least 16 people Bus with at least 30 people A vehicle for transporting disabled people with at least 1 person A student transport vehicle

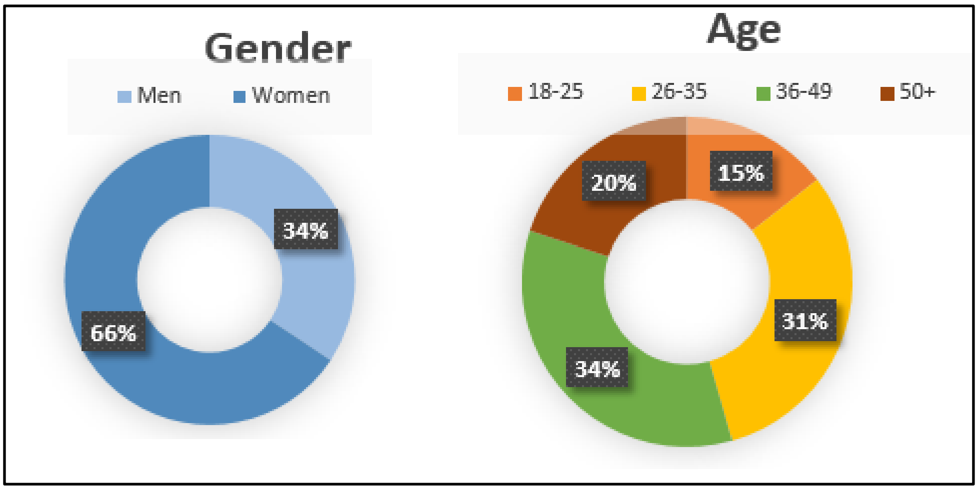

Figure 1. Research participants by gender and age

Algorithm 1: *createTimingByPrioritie*s(array [4][] carPriorities)
Input: a 2-D array of car priorities
Output: an array of time settings for every conflict side of the junction

1. *AVG_CAR_TIME*🡐3
2. *AVG_CONFLICT_SIDE_TIME*🡐30
3. *timeSettings*🡐 new array (4)
4. *totalPrioritySum*🡐0
5. For each conflict side *CSi* where 1≤ i ≤ 4 in *carPriorities* initialize attribute of total time:
   5.1. *tti* 🡐 0
6. For each conflict side *CSi* where 1≤ i ≤ 4 in *carPriorities* search for an emergency priority ('A'):
   6.1. For j🡐0 to *carPriorities[i]*. length do:
      6.1.1. *CSi,j* 🡐 *carPriorities[i][j]*
      6.1.2. *If CSi,j*='A' (for emergency priority - total time is *AVG_CAR_TIME* * No. of cars in the conflict side that block the emergency vehicle) :
         6.1.2.1. *tti* 🡐 *AVG_CAR_TIME* * j
7. For each conflict side *CSi* where 1≤ i ≤ 4 in *carPriorities* set attribute of total car priorities and update the total sum:
   7.1. *tcpi* 🡐 $\sum_{j=0}^{|car\ Priorities[i]|}$ *carPriorities[i][j]*
   7.2. *totalPrioritySum*🡐*totalPrioritySum* + *tcpi*

8. For each conflict side *CSi* where 1≤ i ≤ 4 update the total time attribute (*tti*) by the relative part from *totalPrioritySum*:
   8.1. If tti = 0 (meaning, there is no emergency vehicle in the conflict side):
      8.1.1. tti ← *AVG_CONFLICT_SIDE_TIME* * 4 * (*tcpi / totalPrioritySum*)
9. For i←0 to *timeSettings*.length do:
   9.1. timeSettings [i] ← tti
10. Return *timeSettings*

2.4 Explanation and complexity analysis

For the algorithm we take n as the total number of cars in the junction. Steps 1 to 4 are initializations of the constants of average conflict side (step 1) and single car (step 2) given times (green times), and the variables of the time settings array (the result of the algorithm - step 3) and the total priority sum of all the cars at the junction (step 4). The complexity of these steps is *O (1).* Step 5 is the initialization of the total time for each conflict side. Its complexity is also *O (1).* Step 6 iteratively goes over all of the cars at the junction, looking for emergency vehicles. Since we go through all of the cars the complexity of this stage is *O (n).* Step 7 is the summation of priorities in each conflict side. Since we go through all of the cars again the complexity of this stage is also *O (n*). In step 8 we calculate the total time (green time) given for each conflict side by its relative part in the total priority sum of the junction, whilst the total time for the junction is *AVG_CONFLICT_SIDE_TIME* * 4, meaning 120 seconds. This calculation is done 4 times; thus, the complexity of this step is *O (1).* In step 9 we update the time settings array with the given time for each conflict side, and the complexity of this step is *O (1).* In step 10 we return the time settings array. Hence, the total complexity of the algorithm is *O (n).*

2.4.1 Completeness/ Correctness

2.4.1.1 Initialization

For i = 1, the invariant is respected: in the first iteration, tt1 could be either *AVG_CAR_TIME* * j, for j←0 to *carPriorities[0]*.length if there is an emergency priority ('A') in CS_1, or *AVG_CONFLICT_SIDE_TIME* * 4 * (tcp_1 / *totalPrioritySum*) if 'A' is not in CS_1 .

2.4.1.2 Maintenance

For i = k, given 1 ≤ k ≤ 4, without loss of generality we take *CSk* as the conflict side currently handled. There are two possible cases for this kth iteration:

a. There is an emergency priority ('A') in *CSk:* *ttk = AVG_CAR_TIME* * j, for j←0 to *carPriorities[k-1]*.length, and *CSk*+1 will be checked next.

b. There isn't an emergency priority ('A') in *CSk:* *ttk = AVG_CONFLICT_SIDE_TIME * 4 * (tcpk / totalPrioritySum),* and CS_{k+1} will be checked next.

Thus, the invariant is preserved.

2.4.1.3 Termination

At the last iteration, given i=4, the two options above are the same for CS_4, and equal to tt_4. The process achieves termination since the iterations are allotted to 4 preordained conflict sides in which a total timing solution is guaranteed. Hence the algorithm gives us the array of total timings for every conflict side, as expected.

3 Results and Discussion

To demonstrate the algorithm of the smart junction with social priorities (Algorithm 1) we have implemented it in a web-based JavaScript simulator that allows the user to insert the input of the priorities of each conflict side in the junction.

The junction's lanes are presented in Fig.2. The car priorities are scaled from 0 to 9, 9 being the top priority.

The simulator includes an emergency priority (A). The calculation of a conflict side with an emergency priority is done by its location - calculating the number of vehicles from the junction to it (inclusive), giving each vehicle its allotted time, whilst the calculation of a regular conflict side (without an emergency priority) is done by its relative priority portion, as explained in the algorithm's description.

The conflict sides are: Conflict side 1: lanes C+G, Conflict side 2: lanes A+E, Conflict side 3: lanes H+D, Conflict side 4: lanes F+B. For example: if in conflict side 1, in lane C there are 4 cars with priorities 3, 4, 6, 7 and in lane G there are 4 cars with priorities 9, A, 6, 8, the input in conflict side 1 would be: 3,4,6,7,9,A,6,8.

The estimated basic timing for a single car is 3 seconds, and for a conflict side (in a regular non-smart junction) is 30 seconds.

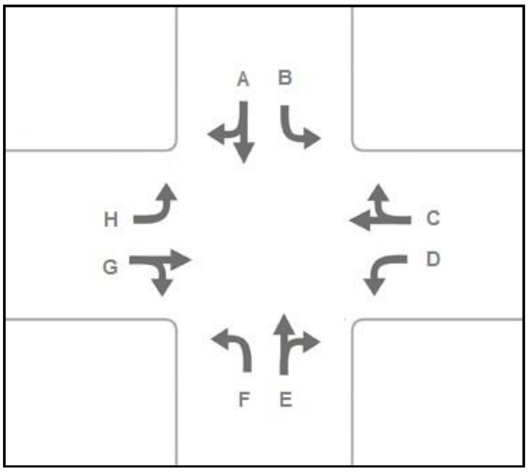

Figure 2. The lanes of the smart social junction's conflict sides

In table 2 we juxtapose the 3 different types of junctions: the regular junction that gives the same time slot to every conflict side, the smart junction that gives the timing slot for a conflict side solely by its traffic load (hence, by its number of vehicles in the queue), and our smart social junction that prioritizes the different lanes and schedules their green times by the nature of the vehicles in the queue.

We can see in the table that for Conflict side 1 there is an emergency vehicle that is 6th in line; thus its time slot is 18 sec. (3 sec. per vehicle).

We can see a difference between the timings of the different methods in conflict side 3 that has the top priority sum: instead of waiting 60 sec. in a regular junction and then getting 30 sec. green time, or in a smart junction waiting 66 sec. and getting 39 sec. green time, in the smart social junction it waits only 48 sec. and gets 42 sec. green time. More comparative results are shown in table 3.

Table 4 presents the average preference for different vehicle types, sorted by priority preference in descended order. We can see a difference in social preferences ranging from 3.99 for Uber taxi up to 9.75 for Rescue car.

Table 2. Time settings comparison for a regular junction, smart junction and smart social junction, No.1

Junction timing method /Conflict side and priorities	**Conflict side 1 (C+G). priorities: 3,4,6,7,9,A,6,8;**	**Conflict side 2 (A+E). priorities: 9,7,8,1,4,5,1,1,3 ,4,5,6,1,3;**	**Conflict side 3 (H+D). priorities: 7,6,8,9,8,9,5,6,4 ,5,6,2,5;**	**Conflict side 4 (F+B). priorities: 6,7,8,4,3,2,4,6;**
Regular junction	30 sec.	30 sec.	30 sec.	30 sec.
Smart junction	24 sec.	42 sec.	39 sec.	24 sec.
Smart social junction	18 sec.	30.13 sec.	41.58 sec.	20.78 sec.

Table 3. Time settings comparison for a regular junction, smart junction and smart social junction, No.2

Junction timing method /Conflict side and priorities	**Conflict side 1 (C+G). priorities: 3,4,6,7,9,1,5,8,6,8;**	**Conflict side 2 (A+E). priorities: 9,7,8,3,A,5,1,1,4,4,5,6,1,3;**	**Conflict side 3 (H+D). priorities: 1,1,1,3,2,2,5,6,4,5,1,2,5,2;**	**Conflict side 4 (F+B). priorities: 6,7,6,4,3,2,8,6;**
Regular junction	30 sec.	30 sec.	30 sec.	30 sec.
Smart junction	30 sec.	42 sec.	42 sec.	24 sec.
Smart social junction	33.2 sec.	15 sec.	23.3 sec.	24.47 sec.

Table 4. Average social preference by vehicle type sorted by social preference value

Rescue car	9.75
Car with Seriously injured	9.72
Car with a woman in labor	9.45
Car with moderately injured	7.98
Student transport vehicle	6.60
Public bus	6.54
Car with 1+ disabled person	5.86
Bus with 30+	5.79
Service Taxi	5.48
Minibus with 16+	5.19
Private car 4+	4.5
Private taxi	4.21
Uber	3.99

Table 5 presents the results of paired t-tests performed for each adjustment priority preference value.

Table 5. Paired-T-test results performed for each two adjacent columns

Rescue car	**Car with seriously injured**	**Car with a woman in labor**	**Car with moderately injured**	**Student transport vehicle**	**Public bus**	**Car with 1+ disabled person**
$t_{229} = 0.519 sig = 0.604$						
	$t_{229} = 3.994 sig = 0.00$					
		$t_{229} = 6.289\ sig = 0.00$				
			$t_{229} = 6.289\ sig = 0.00$			
					$t_{229} = 3.47\ sig = 0.001$	

Table 5. (Continued): Paired-T-test results performed for each two adjacent columns

Car with 1+ disabled person	**Bus with 30+**	**Service Taxi**	**Minibus with 16+**	**Private car 4+**	**Private taxi**	**Uber**
$t_{229} = 0.356\ sig = 0.772$						
	$t_{229} = 1.806\ sig = 0.072$					
		$t_{229} = 1.806\ sig = 0.072$				
			$t_{229} = 5.14\ sig = 0.00$			
				$t_{229} = 5.015\ sig = 0.00$		
					$t_{99} = 1.317\ sig = 0.191$ *	

*Although the average priority preference of the Private Taxi and Uber was similar (4.21 and 3.99), t-tests with all 230 results were significant. We speculated that the small difference was significant due to sample size. Performing the t-test on a randomly selected 100 cases, was not significant. The t-test was significant when running the test on 100 cases for all other significant results.

Both tables show that the Rescue vehicle and the Car with seriously injured person received the highest social preference, averaging 9.75 and 9.72, respectively.

Vehicles which are related to emergency situations, such as vehicles with a seriously injured person (9.72), a woman in labour (9.45) and a moderately injured person (7.98) were the second most highly rated group. Vehicles with a seriously injured person had a higher priority rating than for with a woman in labour. Vehicles with a woman in labour had a higher priority rating than with a moderately injured passenger.

Public transport received higher priority than private transport. Public buses and service taxis received 6.54 and 5.48, respectively, while private taxis and Uber received 4.21 and 3.99, respectively.

The number of passengers in the vehicle had a positive correlation with priority preference. The priority preference was higher when the number of vehicle passengers was higher. The priority preference order was: public bus (6.64), bus with 30+ (5.79), minibus 16+ (5.19), and private car 4 + (4.5). It is exceptional to note the non-significant difference between the public taxi (5.48) and the minibus 16+ (5.19).

Special vehicle characters were examined. A vehicle with a 1+ disabled person received a relatively high rating (5.86), regardless of the small number of passengers. A student transport vehicle received a high rating (6.60), similar to a public bus (6.54). This can be related to a high expected number of passengers.

4 Conclusions and Future Work

In this paper we have presented an algorithm that controls traffic light timings by considering social priorities, analysed its attributes and presented its proof of correctness and complexity, as well as simulation results. We also combined these results with a real-life social preferences questionnaire that we conducted, and analysed the results.

The conclusion we have reached in this paper is that the proposed concept and algorithm could significantly improve current smart junction implementation of timing scheduling, and can be used to reduce traffic loads taking into consideration important social aspects - a subject that was not seriously addressed up to this point. The simulation and questionnaire results have shown that the preliminary assumption of the need for such an algorithm does exist, and its manifestation in a smart junction could help the drivers at traffic junctions from a community aspect that could be life-changing.

The implementation of the algorithm in a real-life traffic junction could be handled within smartphone or smart car software that connects to road sensors, as suggested in [10]. A more interesting option for validating the social preferences more proficiently is the one suggested in [5] and is in the form of biometric authentication. The validation itself could be easily implemented similarly to in smart calendar applications, in which a certain institute, such as a hospital, government office etc. can give a schedule validation to meetings and appointments. The current problem in implementing this algorithm is the validation of the data, which demanded high complexity that involves database connectivity to all of the institutes mentioned above; this subject should be treated in future research.

Future work could include expanding this algorithm and simulation system to other aspects that involve human queue implementations, such as medical appointments in a hospital, organ transplant lists, etc. Investigating other interesting directions that involve these aspects is work currently in progress.

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