# Multi Agent Flow Control in Roundabout Using Self-Organization Technique

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**Abstract:** In this paper, ways of improving the performances of roundabouts under the assumption that the Advanced Vehicle System is proposed. The situation on a road contains uncertainty and complexity caused by different vehicles having different directions and time-varying traffic flow. This sort of system with high uncertainty is called Multi Agent System (MAS). The MAS is a collective system, including numbers of agents and performs high diversity of the configuration as well as it has nonlinear property and complexity. Hence it is difficult to analyze and control the multi-agent system. A roundabout can be considered as an MAS with numbers of moving vehicles. So it must be difficult to use a centralized control technique to all vehicles in an intersection. Therefore, to improve the performances of roundabouts, multi–agents flow control algorithm for vehicles in Roundabouts using 'self-organization' technique is proposed.

**Keywords:** Multi agent system, Self organization, Roundabout, Traffic flow control

## 1. INTRODUCTION

A Rotary system is a kind of intersection, which was built in the states for the first time and was adopted in France and the U.K. Different from typical signalized intersection, a rotary has an advantage that there's no discontinuity of flow and almost no delays due to the slow traffic flow caused by the placement of a central island in the center and the slow traffic guarantees better safety because of the one-way of traffic flow. On the contrary to these advantages, the rotary system has disadvantages. It has relatively low traffic capacity than signalized intersection as vehicles in the rotary have different way-outs. Moreover, in a heavy traffic circumstance, a locking problem may occur, which is the holding up of traffic. In the states, the original rotary system has been almost not being used because of those disadvantages.

Nevertheless, the Locking problem was resolved in the U.K. by establishing an Off-side priority rule. The Off-side priority rule, which is the opposite to the existing the Near side priority rule, is a concept of traffic flow rule that a vehicle yields its traffic priority to the car placed the farthest from its direction. That is, a vehicle about to enter a rotary should yields its priority to the circulating vehicles already in the central island and this means that the vehicle being in the central island has a higher priority to the one which is not. By applying this rule, the Locking-problem was resolved so that higher traffic capacity and safety in the rotary system were enabled. This novel traffic system proposed in the U.K. first emphasized a new type of rotary system and it is called 'Roundabout' or 'modern Roundabout.' [1]

Even though we don't have the Off-side priority Rule here in Korea and it is not highly expected that the rule will not be obeyed even if we have it. Consequently, we have no modern roundabout systems in this country. But it is expected that there will be a significant number of establishing roundabouts because it has many advantages below. [2]

- Safety: a roundabout has low possibility of collision caused by its structure which makes vehicles drive slowly and round in it.
- Increase of capacity: the capacity of a roundabout can be maximized as long as it doesn't have extremely heavy traffic because there is no 'stop' sign in a roundabout while it has only 'yield' sign. In addition, since it has no traffic signals inside, there will be no time spent for waiting signals.
- Decrease of delay: In the circumstance having the same traffic, delays in a roundabout system are occurred less than a signalized intersection because there's no wasting time for the signal waiting.
- Etc.
  Cut down of expenses in constructions and maintaining
  Reduction of noise from vehicles

On the other hand, there are always possibilities of problem occurrences caused by vehicles not able to enter in the 'Gap acceptance.' Those problems possibly caused by unskillful drivers or higher traffic flow over the traffic capacity may lead to the traffic jams or even traffic accidents. To resolve these problem, an extensive number of experiments that covers 'waiting modeling' of vehicles entering a roundabout with Gap acceptance function, designing roundabouts having better performances and evaluating those models by computer simulations with the consideration of real world traffic amount. [3-8]

It is obviously expected that the traffic in urban areas will be persistently increased. Therefore, the needs of researching ways how to increase traffic capacity and reduce delays within not losing safety in developing an Advanced Vehicle System (AVS) or Advanced Highway System (AHS) are highly emphasized as well as researching about development of more efficient road system like roundabouts.

In this paper, we would like to propose ways of improving the performances of roundabouts under the assumption that the AVS system is applied to vehicles so that communications and self-driving of vehicles are already realized.

The situation on a road contains uncertainty and complexity caused by different vehicles having different directions and time-varying traffic flow. This sort of system with high uncertainty is called Multi Agent System (MAS).

The MAS is a collective system, including numbers of agents and performs high diversity of the configuration as well as it has nonlinear property and complexity. Hence it is difficult to analyze and control the multi-agent system. A roundabout can be considered as an MAS with numbers of moving vehicles. So it must be difficult to use a centralized control technique to all vehicles in an intersection. Therefore, to solve the problems of intersection, multi–agents flow control algorithm for vehicles in Roundabouts using 'self-organization' technique is proposed in this paper.

## 2. ENTERING ALGORITHM BASED ON SELP ORGANIZATION

'Self-Organization' is discussed in wide area of research field, such as biology, physics, sociology and computer science. In this paper, its concept is generating and maintaining a functional pattern through the local interaction among neighboring individuals inside a system without any exterior stimulation or constrain. [9] That is, if a behavior of vehicle in the roundabout could be modeled by basic driving and communication rules, the same rules are possibly applied to the others. Since it is almost impossible to attain the exact dynamics of a nonlinear system, a complicated control rules or a centralized controller such as traffic signals might be difficult to be applied so that the 'Self-Organization' could be more effective method in controlling each vehicle. Considering these ideas, the Self Organization rules of a vehicle's behavior in an intersection are proposed as below:

**Self organization rules**

Rule 1:
If a desired position is empty, enter the intersection.
Rule 2:
If being on the circulating path, keep the given velocity limit.
Rule 3:
If being on the circulating path, inform my position to others until getting out of the path.

These self organization rules are the main ideas to construct the Entering Algorithm.
Fig. 1 provides that the entering process must be done by only vehicles which are entering, not by circulating vehicle. The entering vehicles have to choose a sufficient empty space called 'the Acceptance Gap' between other vehicles in the circulating path. Once a vehicle determines its entering spot, it tries to enter the intersection carefully. On the other hand, the circulating vehicles are not in consideration of the entering vehicles and just send data containing where they are.

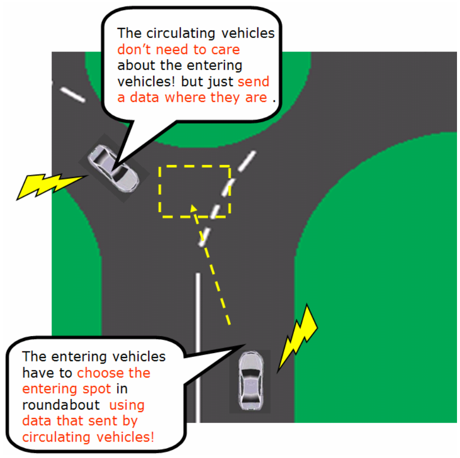


Fig. 1. Basic entering algorithm

By the way, an entering spot might be too close to enter in few seconds. Therefore, an entering vehicle has to choose a farther locating empty space as an alternative than the space in the situation shown in Fig. 1.
Fig. 2 represents the case of the interest section relocated to a farther section. This enables the entering vehicle to have a sufficient time interval for entering. Assume that an entering vehicle passes in the entry of the intersection at time t0 as depicted in Fig. 2, the position A, the desired entering spot, possesses an acceptance gap shown with the dashed-line box. The traffic flow of the central island is at uniform velocity in the counterclockwise direction, so does the position A. Therefore, at time t1, the entering spot is located at the position B, which was located at the position A at time t0. Let L1 be the distance from the entering spot to position B, and L2 be the distance from the entering vehicle to position B. If the entering vehicle is controlled so that L2 is equal to L1 until time t1, the entering vehicle has no problem to enter in the circulating path.

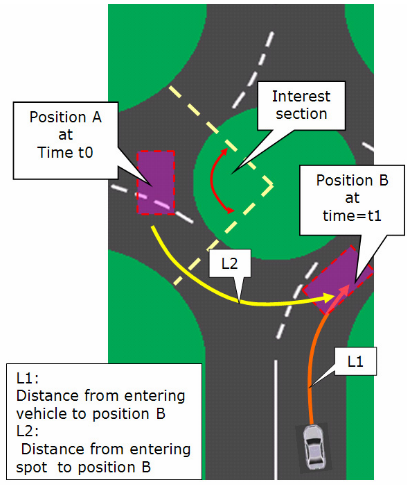


Fig. 2. Entering algorithm based on self organization rules

But, another problem might occur in this case. In Fig. 3, if vehicle 0 selects its entering spot at time t0 in priory to vehicle 1, the entering spot of vehicle 0 is shown as a position A in Fig. 3. At time t1, the vehicle 0 is about to enter the spot. Meanwhile, vehicle 1 newly trying to enter the circulating path, regards the entering spot previously selected by vehicle 0 as an empty spot and might select the same entering spot with vehicle 0. Where, the problem that different vehicles select the same spot could occur. To resolve this problem, 'The Fake date' rule can be added to the existing entering algorithm.

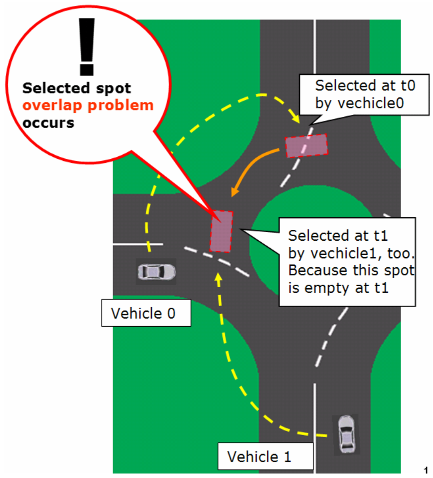


Fig. 3. Overlapping problem

In accordance with the 3 rules presented above, all entering vehicles use the data received from the circulating vehicles to search theirs empty spaces. In Fig. 4, the entering vehicle 0 determines its entering spot and then sends 'the fake data' as like the entering vehicle exists at its entering spot. In this case, vehicle 1 which receives the fake data is not allowed to select the entering spot of vehicle 0. Consequently, considering this idea, the self organization rule 4 is newly proposed below.

Rule 4:
If my entering spot is already selected, send fake data to keep others' not to select their entering spots until my arriving at my entering spot.

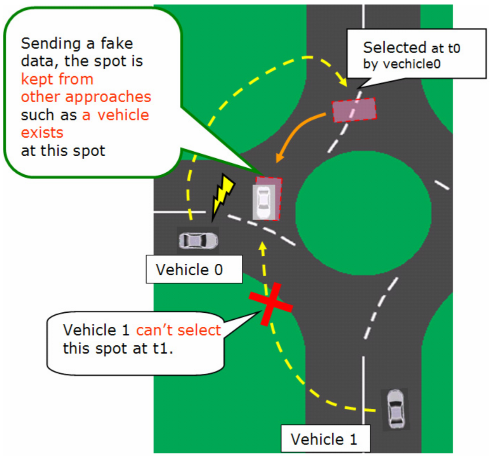


Fig. 4. Description to Rule 4

At this time, shown as Fig. 5, at time t0, the entering spot of a vehicle is not empty. In this case, the vehicle is not allowed to select the spot according to the rule 1 since the spot is not accessible at time t0. However, the entering spot will be empty at time 1 so that the vehicle originally could reach there. Because another vehicle at the interest section at time 0 will get out of the circulating path and will not be there at time 1. This causes wastes in time and capacity. Therefore the rule 1 is needed to be modified as below:

Rule 1':
If a desired position is currently empty or will be soon, enter the intersection.

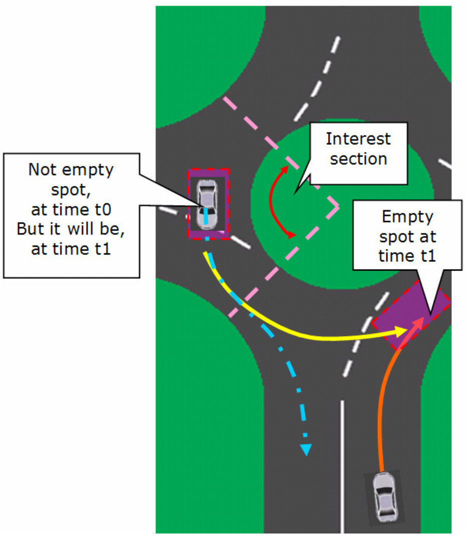


Fig. 5. Description to modified Rule 1

By applying this modified rule 1, the entering vehicle could select its entering spot even if it is not available at the time when it tries to enter the spot. This keeps resources of the roundabout not to be wasted. Finally, the entire four self organization rules are completed in the next sentences.

**Modified self organization rules**

Rule 1':
If a desired position is currently empty or will be soon, enter the intersection.

Rule 2:
If being on the circulating path, keep the given velocity limit.

Rule 3:
If being on the circulating path, inform my position to others until getting out of the path.

Rule 4:
If my entering spot is already selected, send fake data to keep others' not to select their entering spots until my arriving at my entering spot.

The entering algorithm composed of these self organization rules above is depicted as a flow chart in Fig. 6. Using the proposed entering algorithm, simulations were conducted.

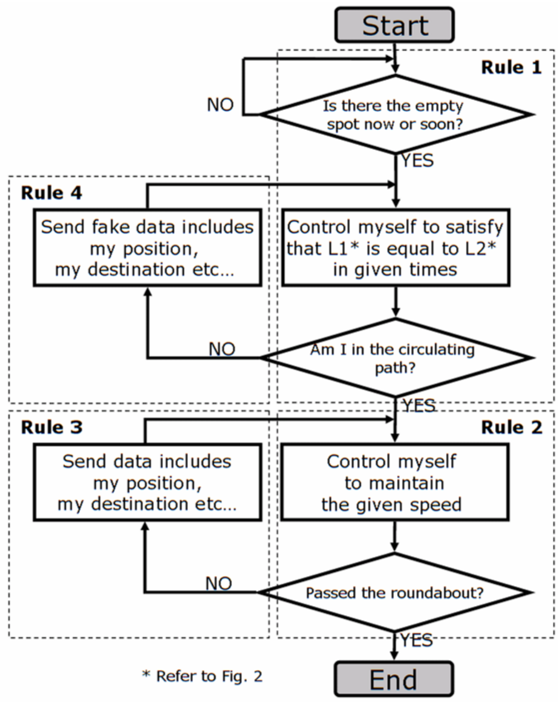


Fig. 6. Entering algorithm flow chart

## 3. Modeling of the intersection and vehicles.

The specifications, used in the designing the roundabout and the vehicle for the simulations are presented follow. According to the guide of roundabout [10], the roundabout and the vehicles are designed.

Virtual roundabout
- Mini roundabout type
- 4 leg
- Single lane
- Flow velocity around the central island: 25km/h
- Maximum entering speed: 25km/h
- Each leg has a waiting queue of size 10

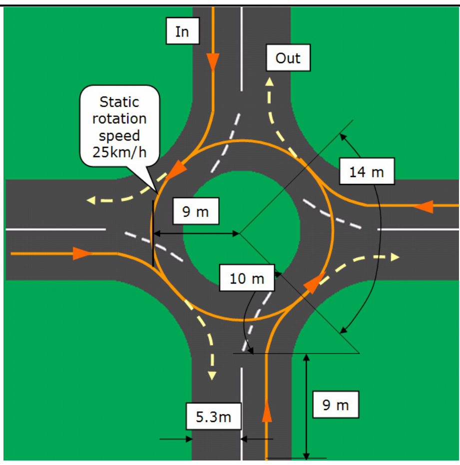


Fig. 7. Specifications of the designed virtual roundabout

This virtual intersection is designed based on the 'mini roundabout' and influential design factors of the roundabout's performance are mainly reflected to the design. Fig. 7 provides the geometric design specifications of this roundabout. In this figure, the solid line indicates the path of the vehicles. The entire path is composed of 20 sub-paths. The circulating path in the middle of the intersection has 9 meters radius and 4 sub-paths. Each entry path has 19 meters length and 2 sub-paths. Therefore the 4 leg path has 16 sub-paths. All vehicles in the circulating path have to keep fixed velocity at 25km/s, the entering vehicles also have the same limit of velocity to satisfy the Offside priority Rule which doesn't obstructs flow of the vehicles in the circulating path. The vehicles having stop delays until entering the roundabout are modeled with a waiting queue of size 10. If a vehicle which just arrives is currently not allowed to enter the intersection because of the heavy traffic, the vehicle waits its entering turn in the waiting queue. Ideally, the larger size the waiting queue has, the more accurate experiment results the simulation would be expected to have. However, in our experiments the suitable size of the waiting queue is limited to the size of ten for the faster simulation speed. In fact, this limit of queue size doesn't cause any serious problem by discarding the incorrect data from the analysis of the experiment results.

Virtual Vehicle

- All vehicles have the same condition
- Sedan type
- Maximum acceleration: 3.92 ($m/s^2$)
- Possible velocity range: 0~90 (km/h)
- Velocity variation: V(k+1)= V(k)+ acceleration(k)*k (1)
- Position variation: S(k+1)= S(k)+ V(k) (2)
- Controller for entering: PD controller
- Controller for cruise: PD controller
- Controller for maintaining the given interval: PD controller
- Communication: Ideal communication condition

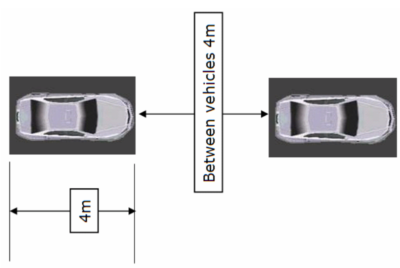


Fig. 8. Specification of the designed virtual vehicle

The models of vehicles used in the experiments are designed as simple as possible so that they have average performances of exiting sedan excluding specific cases, because the improvement of the roundabout itself is mainly focused on in this paper. Maximum acceleration, the most important performance factor of vehicle, is ideally assumed about 4 m/s2 at all range of velocity domain and keeps the speed not to be over 90km/h. At this maximum acceleration, the modeled vehicles take about 25 seconds to reach from the stopped state to the state of 100 km/h. And the two simple equations, shown in (1) and (2) expressing the velocity, the acceleration and the distance are applied to model the dynamics of the vehicle. Entering of a vehicle which enters its entering spot is controlled by a typical PD controller, and so is maintaining the given interval and speed. Lastly, the communication of the vehicles is conditioned to be ideal so that there is no delay, no noise and no collision. Under this condition, all vehicles are able to have the ideally stable communication to each other.

## 4. MEASUREMENT AND SIMULATION CONDITION

Multi Agent System Simulator (MASS) is programmed to simulate the proposed entering Algorithm according to the design specification described above by using Visual c++ programming tool. By changing a traffic variation rate, a traffic variation type, 3 types of turn (left turn, right turn, U turn) rates and other simulation parameters, many useful data of measurement are obtained through the simulating the MASS program. Among the data, the volume to capacity (V/C) ratio and the delay are important in evaluation of an intersection's performance in the level of service's point of view. [9] V/C ratio represents the ratio of the quantity being used by vehicles to the whole capacity. The volume is the total number of vehicles which pass through the intersection in a specific time interval. And the capacity is the maximum volume that an intersection possibly has. The smaller V/C ratio an intersection has at the same condition, the better performance the intersection has. The delay is correspondent to the average delay experienced by all vehicles from arriving at the waiting queue of intersection to passing through out, measured every 30 seconds.

Simulation is conducted about two conditions. First, in Simulation I, three types of controlling models are considered. They are: the human drive in roundabout (HRA), the entering algorithm applied roundabout (ERA) and the modified entering algorithm applied roundabout (MERA). Then they are compared each other under the same condition. The ERA and MERA are modeled based on the AVS, which HRA is not yet. In real roundabout, it is hard for most drivers to get in between two circulating vehicles having the speed of 25km/h and the interval of 8 meters. That is, HRA has worse performance than MERA. Therefore, HRA is modeled in the direction to have the additional limitations to the MERA model. In other words, MERA imitates HRA by let the performance of modified entering algorithm down. The limitations are described below.

The interest section of Fig. 5 becomes broaden as shown in Fig. 9 And the entering condition is changed so that the driver may get in the circulating path only if the vehicles in the new interest section do not currently exist or are expected through out soon. As a result, entering enable provability get smaller as much as increasing of interest section size

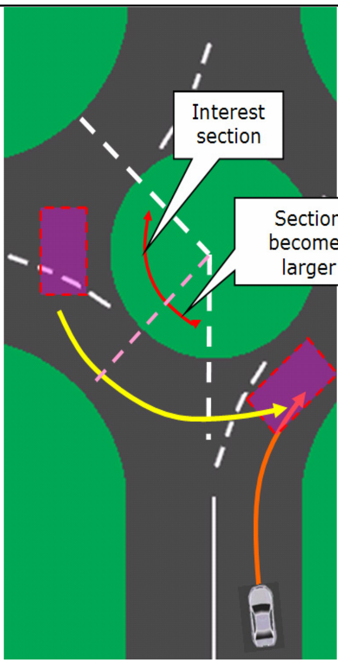


Fig. 9. Interest section of human Drive in Roundabout

In Simulation II, as the traffic characteristic is changed, 3 simulations for each type of the roundabout is conducted at different characteristics. For example, the ratio of the left turn to traffic volume varies from 10 % to 30 % for the case of each simulation. The results of this experiment show the sensitivity of the roundabout to this variation.
Each experiment is simulated for 100 minutes and the input traffic volume is elevated from 0veh/hr to 8000veh/hr at interval of 800veh/hr and each 10 minutes.
(veh/hr: vehicles per hour)

## 5. SIMUALTION RESULTS AND EVALUATIONS

### 5.1 Simulation I

Condition:
- Volume ratio by approach of 1:1:1:1
- Left turn percentage of 10 %
- Under 3 types of roundabout (HRA, ERA, MERA)

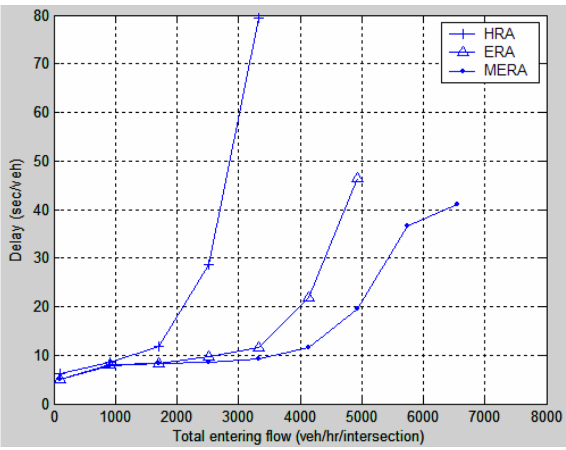


Fig. 10. Comparison of the delays under 3 types of roundabout

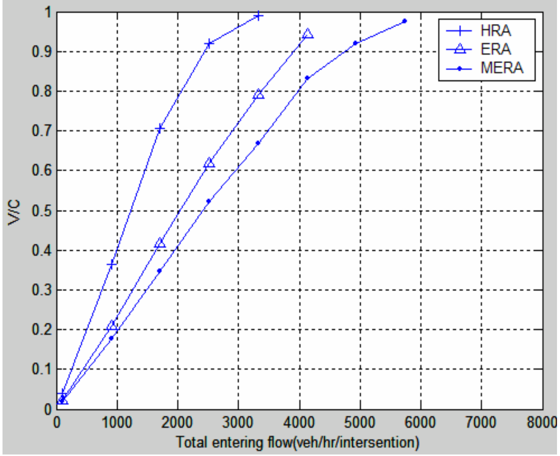


Fig. 11. Comparison of V/C under 3 types of roundabout

Fig. 10 and Fig. 11 provide comparisons for 3 types of roundabouts. The results clearly show that the MERA has the best performance among them. This experiment is simulated under the same condition as much as possible with other simulation research using SIDRA software for the comparison. [3] Fig .12 simultaneously shows the performances of HRA, ERA, MERA and SIDRA used for the roundabout (SRA). In the research, not only roundabout but also signal control, two-way stop control and four-way stop control are simulated using SIDRA under various traffic conditions. Among those simulation results, only the case using the single lane roundabout which has 4 legs, left turn percentage of 10 % and volume ratio by approach of 1:1:1:1 is chosen and compared with this simulation using MASS under the same condition.

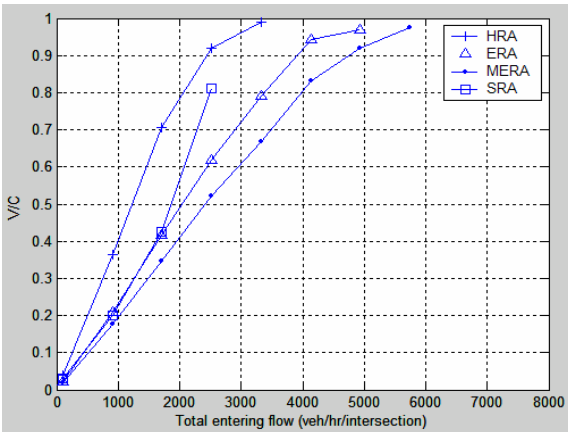


Fig. 12. Comparison of V/C under 4 types of roundabout

As indicated in the results of Fig. 12, SRA has a better performance than HRA but worse than the others. And it is noticed that ERA and MERA based on the self organization rules posses better traffic service level than SRA.

### 5.2 Simulation II

Condition:
- Volume ratio by approach of 1:1:1:1
- Varying Left turn volume (10 %, 20%, 30%)
- Under 3 types of roundabout (HRA, ERA, MERA)

Fig. 13 demonstrates the V/C sensitivity of each roundabout about left turn variation and Fig. 16 represents the delay sensitivity. In general, the increase of a left turn volume makes the performances of all roundabouts become worse. Especially, the MERA has the worst sensitivity at heavy entering flow over 5000 veh/hr. Because the left-turning vehicles take more times than through-moving vehicles and right-turning vehicles, the left turning vehicles lower the capacity of the circulation lane. Nevertheless, MERA still keeps the best performance.

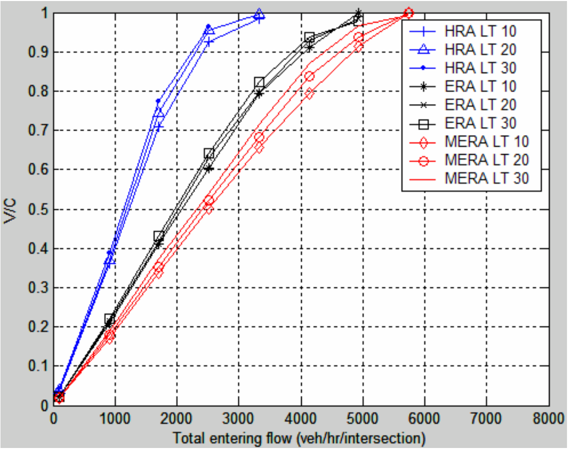


Fig. 13. Comparison of V/C, left turn variation

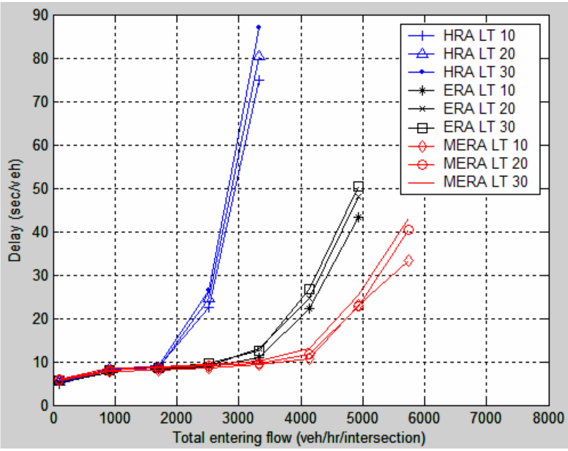


Fig. 14. Comparison of delays, left turn variation

## 6. CONCLUSION

In this paper, a multi-agent flow control in roundabout is proposed. And its performance is evaluated in terms of V/C ratio and delay in comparison to the exiting researches about roundabouts by means of computer simulations. With the experiments performed for the analysis, the modified entering algorithm applied to roundabout shows the best service level in spite of its poor sensitivity to left turn volume variation. In particular, it is remarkable that a multi-agent flow control can be efficiently operated with only some simple rules and just PD controllers. It is also proved that the self organization technique is suitable to model and control a multi agent system.

But there are still restrictions remaining in realizing the proposed method. For instance, MERA requires enhanced infrastructures such as an intelligence vehicle system which enables stable communication and self-driving. In addition, the research about developing an extended entering algorithm covering multi-lanes and heavier traffic volume is still in need and remained for the further research.

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