OPTIMIZATION THE AUTOMATED GUIDED VEHICLES RULES FOR A MULTIPLE-LOAD AGV SYSTEM USING SIMULATION AND SAW, VICOR AND TOPSIS METHODS IN A FMS ENVIRONMENT

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ABSTRACT
In this paper, several pickup/delivery and pickup/dispatching rules have been examined in an automated guided vehicle system which is the biggest set of strategies in the literature. The best control strategy has been determined considering some important criteria such as System Throughput(ST), Mean Flow Time of Parts (MFTP), Mean Tardiness of Parts (MFTP), AGV Idle Time (AGVIT), AGV Travel Full (AGVTF), AGV Travel Empty (AGVTE), AGV Load Time (AGVLT), AGV Unload Time (AGVUT), Mean Queue Length (MQL) and Mean Queue Waiting (MQW). All strategies have been ranked using SAW, VICOR and TOPSIS methods. For this reason, several simulation experiments were conducted to obtain the best solution. As the experimental results show the approach is effective enough to be used in real world environments.

Keywords: AGV, Control strategy, Ranking Methods

1. INTRODUCTION

According to Tompkins and White (1984), about 20%-50% of total operational costs can be attributed to material handling system. As a result, researchers have been looking for methods to minimize their material handing cost. One solution is to automate material handling operations. Because of the rapid advances of automation, computer and control technologies, many automated material handling systems are available to us today [5]. Because of their routing flexibility, automated guided vehicles (AGVs) have been used in many manufacturing systems such as parts manufacturing systems with diverse and complex processing routes, warehouses, dispatching systems, local and international transportation systems, ports and etc [2]. In recent years, there have been many studies on AGV-related problems. Automated guided vehicles (AGVs) are known for their routing flexibility advantage. AGVs are driverless transportation systems that are being used in horizontal movements. The concept was introduced by [1] in 1995. Since that time, several applications have been developed. In designing an AGV system, many tactical (e.g., system design like pickup/delivery or P/D points, the fleet size, flow path layout, etc.) and operational (e.g., routing or dispatching strategies) problems have been addressed. For example, the older ones were addressed by Co and Tanchoco [15], King and Wilson [16], Ganesharajah and Sriskandarajah [17], Johnson and Brandeau [18], Manda and Palekar [19], and Hoff and Sarker [20]. Co and Tanchoco discussed the operational issues of dispatching, routing, and scheduling of AGVs. According to [3], several key points must be considered in designing an AGV system:

- Flow path layout,
- Traffic management for preventing any deadlocks and collisions,
- Position and number of P/D points,
- Fleet size
- Dispatching rules
- Routing rules
- Locating the idle AGVs
- Breakdown management

Despite lots of advantages, AGVs has a famous disadvantage which is being more difficult to be controlled. Many issues need to be resolved in AGV controlling system such as pickup-dispatching problem [4]. The AGV control problem involves determining a place that the AGV should visit in order to perform its pickup or delivery task [5]. One important characteristic of this problem is that a vehicle load in any given route is a mix of pickup and delivery loads [6]. The pickup and delivery problem (PDP), with or without time windows, has been widely studied in the literature by many researchers, from various formulations to several solution methods, have been proposed to deal with different versions of the PDP. Most exact and heuristic methods have been developed to solve real instances of static and dynamic problems under either stochastic or deterministic demand. In most dynamic versions of the PDP (with demand that appears in real-time), it is assumed that the dispatcher manages reliable advanced information with regard to service requests. Over the last few years, the interest in studying the dynamic and stochastic versions of the PDP (associated with dial-a-ride systems) has been grown rapidly, mainly due to the access to communication and information technologies, as well as the current interest in real-time dispatching and routing environments [7]. A multiple load AGV that can carry several loads for pickup or delivery has four major problems. The first problem is the task-determination problem that determines whether the next task is a pickup task or a delivery task. The second problem is referred as the delivery-dispatching problem in which the best delivery point is determined if its next task is a delivery task. The third problem is referred to as the pickup-dispatching problem. In this problem, the best pickup point is selected if its next task is a pickup task. Finally, the fourth problem is the load-selection problem, in which the best load is selected to be picked up from the output queue of a pickup point [5].

Now, the four major problems are defined in more details as follows

1.1. Task-determination problem

In order to select a task between pickup and delivery tasks for a semi loaded AGV, [3] proposed three strategies as follows:

- Delivery-task first (DTF): according to this rule, the AGV must deliver its load first then can pick up another load even in a coincident case when it receives both pickup and delivery requests.
- Pickup-task first (PTF): this rule is the opposite of DTF.

Load ratios (LR): LR can be formulated as follows:
LR= number of loads in AGV/AGV capacity

LR strategy could have several forms in application. An example can be found in Table 1 by [5].

Table 1: An example for LR strategy

Criteria for LR	Probability (%)	Next Task
$0 < LR \ll 35\%$	D P	٣٥ ٦٥
$35 < LR \ll 65\%$	D P	٥٠ ٥٠
$65 < LR < 100\%$	D P	٦٥ ٣٥

According to [5] and [8], it was shown that DTF has the best performance, so this strategy was used in the simulation model. One may define control strategies as follows.

1.2. Delivery-dispatching problem

If the next task is delivery and there are several P/D points in the selected route, in order to determine the best pickup point, one can define some strategies such as: Longest time in system (LTS), Longest Waiting Time At Pick up point (LWTAP), Longest Average Waiting Time At Pick up point (LAWTAP), Shortest Distance (SD), Greatest QUEUE Length (GQL), Earliest Due Time (EDT), Earliest Average Due Time (EADT), Smallest Remaining Processing Time (SRPT) and Smallest Slack Time (SST) according to [5].

1.3. Delivery problem

An AGV faces to this case when it has several loads and it must be determined a P/D point in its route to deliver its loads. According to [5], the same strategies as previous section can be developed.

1.4. Selection problem

If there are several loads in the queue of a P/D point, an AGV must select the best load to be picked up. According [9], because the best strategy is First-In-Queue-First-Out (FIQFO), this strategy was used in the simulation model.

2. SIMULATION MODEL

In the simulation model, some specific assumptions were considered. All vehicles are multiple-load AGVs and the fleet size in the system is 3 units. The flow path layout and all model information are the same as the one which was adopted by [8] and [9] for the best comparison. The flow path layout is shown in Figures 2, 3, and 4 where all paths are unidirectional with the capacity of one unit to prevent any conflicts. In order to unload the loads before picking up more loads from a machine by an AGV, the delivery point and the pickup point of every machine has been arranged. Every machine has a buffer area, at which idle AGVs can stay and wait for pickup requests. All AGVs have the same loading capacity and same speed (1.8 m/s). Parts are placed in the pallets and in each pallet, there is only one type of product and for each part, the production sequence and the Mix-Ratio are known (Table 3). The load-carry capacity of these AGVs is four loads. There are 12 machines in the manufacturing system as mentioned in Figure 2. Workstations 1 and 12 are the entry and sink stations, respectively. The workstations 2–11 are processing machines. The number of part types made in the system is six. Table 4 shows the distribution functions of each machine processing time. It is assumed that parts will go through the same operations on the same workstations. It is also assumed that the setup times are included in the related processing times. Furthermore, in the simulations, a part is assigned with a due time when it arrives at the system randomly. The due time is generated by adding the arrival time with a random number. According to the levels which were shown in Table 2, there are 20 different strategies which will be used in the simulation model as control strategies. We used a coding system for referring any kind of strategies using the capital letters shown in the columns of Table 2. For example, a strategy (or problem) T1P1D1L1 refers to a strategy where the task rule is DTF, the pickup-dispatching rule is LTIS, the delivery dispatching rule is SQL, and the load-selection rule is FIQFO [9]. Meanwhile, in the simulation model, we used NV as a workstation-initiated approach for assigning the AGVs to the next task. In order to evaluate the control strategies, the following criteria were used in the model and the number of each criterion was used as a reference in the simulation experiments:

1. System throughput (ST),
2. mean flow time of parts (MFTP),
3. The mean tardiness of parts (MTP),
4. Percentage of vehicles idle time (AGVI),
5. Percentage of time moving vehicles with full capacity (AGVTF),
6. percent time on moving vehicles with empty capacity (AGVTE),
7. Percentage of load time (AGVL),
8. Percentage of unload time (AGVUL),
9. The average queue length in pickup and delivery points (MQL),
10. The average waiting time in pickup and delivery points (MQW) [9].

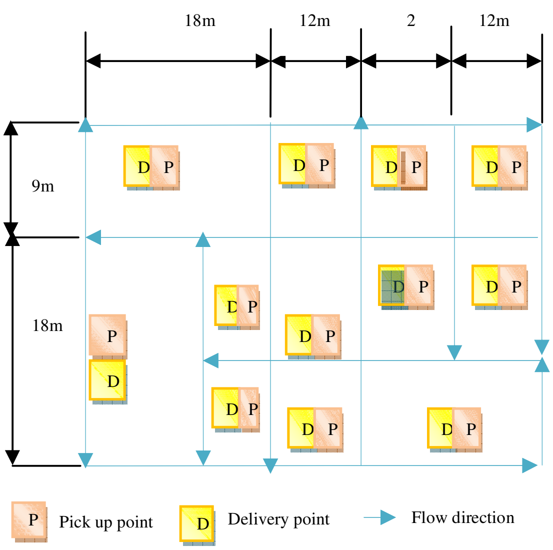

Figure1: The flow path layout

Load-Selection	Delivery-Dispatching	Pickup-Dispatching	Tasks	Levels
FIQFO	SQL	LTIS	DFT	1
	EDT	GOL		2
	SD	EDT		3
	LIQFO	SRPT		4
	FIFO	LWTAP		5
		SD		6

Table 2: The levels of controlling strategies

Table 3: The mix-ratio and process sequence of each part

Part Type	Mix-Ratio	Sequence
1	0.16	1-3-5-7-9-11-12
2	0.17	1-2-4-6-8-10-12
3	0.18	1-4-5-7-9-10-12
4	0.15	1-4-5-7-9-10-12
5	0.14	1-3-4-5-9-11-12
6	0.20	1-2-3-6-8-9-12

All simulation experiments were run by Enterprise Dynamics V8.1 software. The number of replications for each calculation was set at 30 by independent sunburns. The simulation period for each replication was 170,000 seconds. For determining the warm-up period, the throughput criterion was used in 30 runs. The results were shown in Figure 3.

As the figure shows, when the total production reaches 750 units (480,000 seconds), the system reaches a stable state. Therefore, for simulation replications, at first a warm-up period of 480,000 seconds ran then 30 replications were executed afterward for each calculation (Fig. 3). Due to several criteria, we have used the mean of three criteria decision making methods such as VICOR, SAW and TPSIS to evaluate and rank the results for the control strategies (Table 7). Other data has been taken from [9] in Fig. 2 and Table 5.

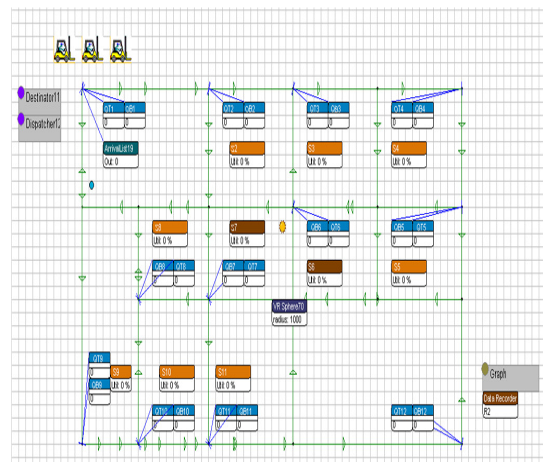

Figure2: Two-dimensional view

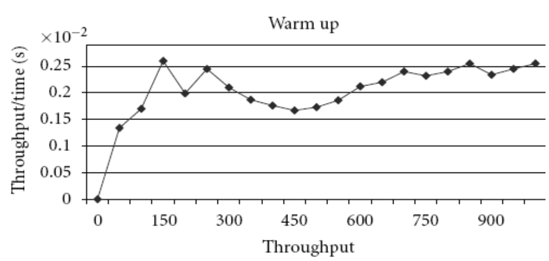

Figure 3: The warm-up diagram

3. COMPUTATIONAL RESULTS

For calculating the weight of each criterion, the experts' views which had been based on a field study were taken. At first, we had some interviews with 10 special experts. All experts were the production managers and the financial mangers of 5 local auto manufacturers which are using multiple-load AGVs in their production sites and the weights are listed in Table 4.

Table 4: The weight of strategies

ST +	MFTP -	MTP -	MQL -	MQW -
16	14	11	15	16
AGVI -	AGVTF +	AGVTE -	AGVL -	AGVUL -
9	4	3	6	6

As the results show, the greatest weights belong to ST and MQW and the lowest ones belong to AGVTE criterion.

Table 5: The processing-time distribution and the production sequence of each product type

Work station	Processing time distribution (min)
2	N (1,0.1)
3	N (1.5,0.15)
4	N (2,0.2)
5	N (1,0.1)
6	N (2,0.2)
7	N (2,0.2)
8	N (1.5,0.15)
9	N (1.5,0.15)
10	N (2,0.2)
11	N (1,0.1)

The results of each ranking methods show in next tables.

Table 7 :Ranking result by SAW method

Rank	Strategy SAW	Grade	Rank	Strategy SAW	Grade
1	21	0.8075	16	14	0.4754
2	23	0.7963	17	13	0.4678
3	25	0.7702	18	16	0.4624
4	22	0.7379	19	18	0.4614
5	24	0.734	20	6	0.4347
6	2	0.681	21	8	0.4269
7	5	0.6799	22	9	0.4186
8	1	0.6787	23	15	0.4104
9	4	0.6781	24	26	0.4081
10	3	0.6721	25	20	0.4077
11	7	0.5113	26	17	0.4072
12	10	0.5041	27	19	0.4028
13	12	0.4825	28	27	0.4026
14	29	0.4781	29	28	0.395
15	11	0.476	30	30	0.3843

Table 8 :Ranking result by TOPSIS method

Rank	Strategy TOPSIS	Grade	Rank	Strategy TOPSIS	Grade
1	21	0.883	16	13	0.5312
2	23	0.8399	17	7	0.5275
3	22	0.8388	18	29	0.525
4	25	0.8381	19	9	0.5008
5	24	0.8334	20	30	0.4865
6	15	0.5855	21	6	0.4837
7	1	0.5789	22	8	0.4807
8	3	0.5781	23	16	0.4776
9	14	0.5758	24	18	0.4736
10	4	0.5738	25	26	0.4626
11	5	0.5707	26	27	0.4626
12	11	0.5706	27	28	0.4584
13	2	0.5706	28	20	0.4571
14	12	0.5628	29	27	0.4534
15	10	0.5567	30	19	0.4201

Table 9-Ranking result by VICOR method

Rank	Strategy VICOR V=0.5s	Grade	Rank	Strategy VICOR V=0.5s	Grade
1	15	0.2807	16	10	0.673
2	22	0.2834	17	29	0.7449
3	21	0.3577	18	7	0.7905
4	23	0.4143	19	6	0.7975
5	24	0.4263	20	8	0.8022
6	25	0.4423	21	30	0.8061
7	12	0.4821	22	16	0.8297
8	14	0.5168	23	9	0.8406
9	11	0.586	24	28	0.8458
10	1	0.5972	25	18	0.8483
11	3	0.6036	26	26	0.8583
12	4	0.6095	27	27	0.8941
13	5	0.6187	28	20	0.9001
14	2	0.6271	29	17	0.9692
15	13	0.6306	30	19	0.9721

According to the results in Table 6, the best strategy regarding ST criterion is T1P2D3L1 and

The worst one is T1P1D2L1, because it uses GQL as pickup-dispatching rule and SD as Delivery-dispatching rule, so these strategies have the greatest influences on the system throughput. Regarding MQW as the second important criterion, the best strategy is *T1P5D5L1* and the worst one is *T1P4D2L1*. Maximum queue length happens when it uses *T1P4D2L1* and the shortest length belongs to the strategy *T1P5D5L1*.

As Tables 7, 8 and 9 shows the best and worst strategy of each method is different because of this reason we have used BORDA method, for combining the result of these three methods.

The main contribution of this paper is using the mean of TOPSIS, SAW and VICOR weights for selecting the best control strategies by mixing them with mentioned weights. The related results were shown in Table 10.

Because, ED 8.1 has several graphical tools, the verification of the simulation model was easy task and regarding the model validation, we compared our model to the one developed by [9]. Because both models have the same parameters, the system throughput must be the same at 95% as the significant level. Because our models results had not Normal distribution and the fact that both models have not been paired with different variances, we used the Smith-Satterwaithe test as the validity criterion. The number of samples was 20 and the p-value of the test was 0.0004 so the H_0 hypothesis was accepted, so both models have the same results.

Table 6- Simulation results

Criterion / Strategy	ST	MTP	MFTP	AGVI	MQW	MQL	AGVUL	AGVL	AGVTE	AGVTF
T1P1D1L1	695.33	358.1344	229.2505	0.00	2097.33	10.63	0.06	0.06	0.53	0.35
T1P1D2L1	688.50	371.2092	231.4515	0.00	2103.86	10.16	0.06	0.06	0.52	0.35
T1P1D3L1	694.30	357.8818	225.8998	0.00	2128.03	11.38	0.06	0.06	0.53	0.35
T1P1D4L1	692.40	365.5618	232.0686	0.00	2083.89	10.65	0.06	0.06	0.52	0.35
T1P1D5L1	690.43	370.8603	226.8865	0.00	2037.88	10.95	0.06	0.06	0.52	0.35
T1P2D1L1	1034.07	16.2724	702.8447	0.02	10455.54	50.42	0.10	0.10	0.47	0.31
T1P2D2L1	1013.33	19.2254	774.6444	0.00	10959.81	52.91	0.10	0.10	0.43	0.37
T1P2D3L1	1036.40	19.02247	704.0995	0.02	10547.30	50.61	0.10	0.10	0.46	0.32
T1P2D4L1	1023.23	24.2128	744.1661	0.01	11060.93	51.79	0.10	0.10	0.44	0.35
T1P2D5L1	1022.73	24.5994	749.2228	0.00	10332.17	42.97	0.10	0.10	0.44	0.35
T1P3D1L1	954.10	86.1634	822.0297	0.00	7664.92	33.76	0.09	0.09	0.49	0.32
T1P3D2L1	1013.90	95.717	782.3533	0.00	8,020.67815	35.9226	0.10	0.10	0.44	0.37
T1P3D3L1	966.6	110.8199	827.92455	0.00	8,546.09154	39.04	0.09	0.09	0.49	0.32
T1P3D4L1	933.70	69.5078	780.081	0.00	7801.11	37.52	0.09	0.09	0.48	0.33
T1P3D5L1	955.27	51.2697	649.5937	0.01	7152.91	38.71	0.09	0.09	0.48	0.33
T1P4D1L1	1,018	18.21646	283.6282	0.03	10794.58	60.67	0.10	0.10	0.47	0.31
T1P4D2L1	1010.07	23.18528	855.147	0.01	11315.18	65.03884	0.10	0.10	0.46	0.33
T1P4D3L1	1,017	19.02247	276.5005	0.03	10902.08	62.83	0.10	0.10	0.46	0.31
T1P4D4L1	1012.47	25.53951	690.31	0.03	11108.33	63.33	0.10	0.10	0.46	0.32
T1P4D5L1	1012.20	25.2164	634.67	0.02	10956.82	62.94	0.10	0.10	0.46	0.32
T1P5D1L1	725.97	29.1373	145.1971	0.00	2087.37	6.60	0.07	0.07	0.52	0.34
T1P5D2L1	750.13	10.2596	210.8495	0.01	1517.19	11.43	0.07	0.07	0.50	0.35
T1P5D3L1	717.80	9.7899	150.8138	0.01	1976.14	6.77	0.07	0.07	0.51	0.34
T1P5D4L1	719.33	11.5195	228.7747	0.01	2027.73	6.63	0.07	0.07	0.51	0.34
T1P5D5L1	711.43	13.7399	148.4764	0.01	2001.99	6.50	0.07	0.07	0.51	0.34
T1P6D1L1	975.80	23.9437	663.6724	0.02	10628.23	59.85	0.09	0.09	0.50	0.30
T1P6D2L1	962.83	26.03228	670.0885	0.02	10814.46	62.67	0.09	0.09	0.49	0.31
T1P6D3L1	973.03	34.0848	652.5999	0.02	10532.46	59.74	0.09	0.09	0.50	0.30
T1P6D4L1	972.93	40.5459	648.8595	0.00	10381.81	59.98	0.09	0.09	0.50	0.32
T1P6D5L1	978.03	53.8118	624.6368	0.01	10363.30	60.69	0.10	0.10	0.48	0.31

According to the final results, the best strategy is *T1P5D1L1* and the worst one is *T1P3D4L1*, that is, when we use LWTAP for pickup dispatching and SQL for delivery-dispatching activities.

Table 10 :Final Ranking result by BORDA method

Rank	Strategies	Grade	Rank	Strategies	Grade
1	21	29	16	13	14
2	23	28	17	7	13
3	22	27	18	29	12
4	25	26	19	6	11
5	24	25	20	8	10
6	15	24	21	30	8
7	6	23	22	16	8
8	3	22	23	9	8
9	14	21	24	18	6
10	4	20	25	26	5
11	5	19	26	28	3
12	12	18	27	17	3
13	11	17	28	20	3
14	2	17	29	27	1
15	10	15	30	19	0

The results show the importance of due time for selecting the best control Strategies. The role of due time in the current consuming market conditions where the market is full of different brands with suitable quality and services is a key factor to keep the customers satisfied by agreed delivery times. For comparison purposes, we selected the study done by [8]. They used 3 criteria and 18 different strategies but here we used 10 criteria and 30 different strategies. They used ANOVA analysis for ranking the strategies, but here, we used TOPSIS together with SAW and VICOR method for ranking them. The approach used here is more close to the real applications where the top managers can change the strategies based on the production, market situation, and financial issues. For another comparison, the best strategy reported by [9] was *T1P2D3L1* and the worst one was *T1P1D3L1*. We have developed more control strategies than [9] and it helped us to find better solutions for some criteria like MQW and MQL. Another important finding is that it is not reasonable to just focus on one criterion. As mentioned in the literature, most previous researches were focused on optimizing the system throughput. According to Table 11 and 6, taking *T1P2D3L1* has the greatest value of system throughput but stands in the 20st rank.

Table 11: Strategies ranking by BORDA method

Strategy	rank	Strategy	Ran k
T1P1D1L1	7	T1P4D1L1	22
T1P1D2L1	14	T1P4D2L1	27
T1P1D3L1	8	T1P4D3L1	24
T1P1D4L1	10	T1P4D4L1	30
T1P1D5L1	11	T1P4D5L1	28
T1P2D1L1	19	T1P5D1L1	1
T1P2D2L1	17	T1P5D2L1	3
T1P2D3L1	20	T1P5D3L1	2
T1P2D4L1	23	T1P5D4L1	5
T1P2D5L1	15	T1P5D5L1	4
T1P3D1L1	12	T1P6D1L1	25
T1P3D2L1	20	T1P6D2L1	29
T1P3D3L1	16	T1P6D3L1	26
T1P3D4L1	9	T1P6D4L1	18
T1P3D5L1	6	T1P6D5L1	21

4. CONCLUSIONS

In this paper, pickup-dispatching problem together with delivery-dispatching problem of a multiple-load automated guided vehicle (AGV) system has been studied. Several different rules of these problems were used to create the best control strategies. For selecting the best strategy several important criteria were considered, such as System, Throughput (ST), Mean Flow Time.

of Parts (MFTP), Mean Tardiness of Parts (MFTP), AGV Idle Time (AGVIT), AGV Travel Full (AGVTF), AGV Travel Empty (AGVTE), AGV Load Time (AGVLT), AGV Unload Time (AGVUT), Mean Queue Length (MQL), and Mean Queue Waiting (MQW), in a part manufacturing system where each part has a due date. The criteria were evaluated by a filed study with 10 experts who work in 5 local auto manufacturing companies to make the results as applicable as possible. For evaluating each criterion, we used three MADM methods: TOPSIS, VICOR and SAW methods. Finally, for ranking and selecting the best control strategy, BORDA method and importance weights were applied.

Here we defined the distances between workstations and calculated the warm-up period in order to make the simulation more practical while the total strategies examined were 30 strategies with 10 criteria which had been the biggest sets tested so far.

The first contribution of the paper is using several criteria for selecting the best control strategy. Most previous researches just focused one or two criteria. The second contribution of the current research is using a large number of control strategies in comparison to latest studies like [8] and [9] that helped us to obtain better results. The results show that the proposed algorithm is efficient and robust enough to be used in applications. Regarding the research limitations, we have not considered the optimization process together with the FMS which can be carried out in future researches.

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