Development of Simulation Model for Transportation Processes of Autonomous Distributed AGV Systems by using AnyLogic

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Distributed architectures of manufacturing systems

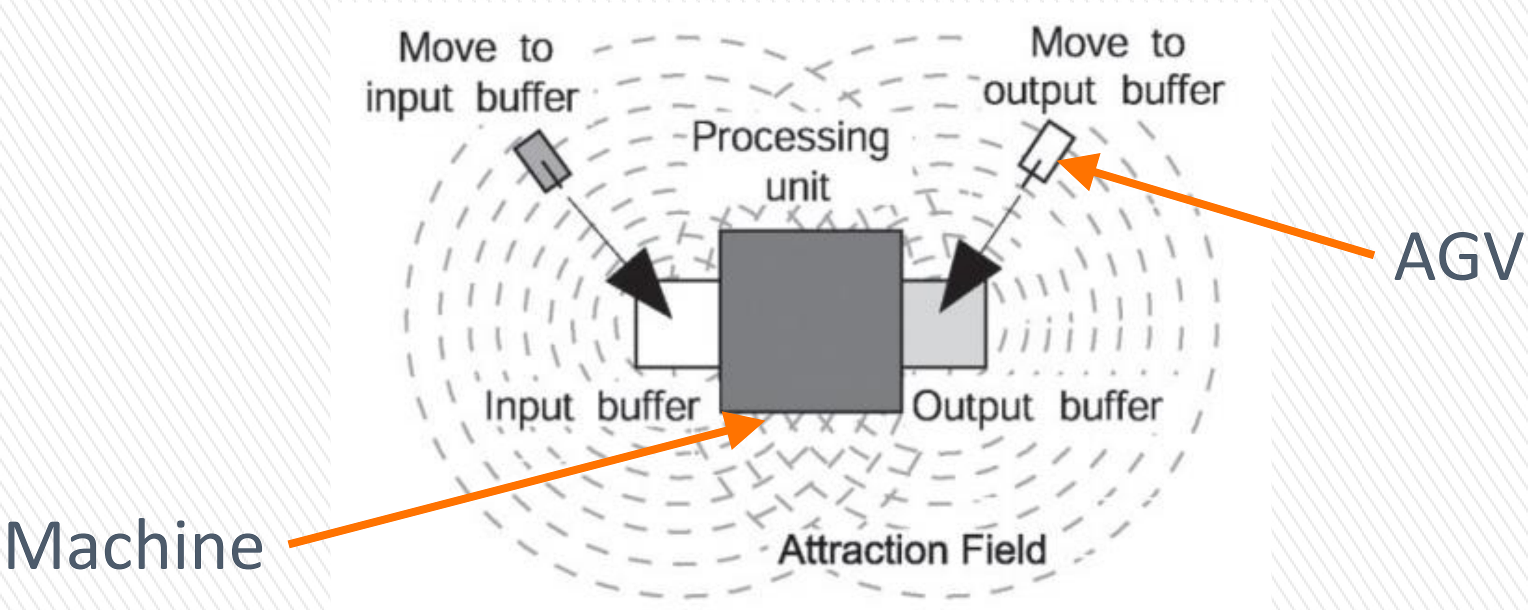
- Autonomous Distributed Manufacturing Systems (ADMS)
- Biological Manufacturing Systems (BMS)
- Holonic Manufacturing Systems (HMS)

They are proposed to realize more flexible control structures of the manufacturing systems, in order to cope with

  - Dynamic changes in the volume and the variety of the products
  - Unforeseen disruptions, such as malfunction of manufacturing equipment and interruption by high priority jobs

Some researches have been carried out to deal with the distributed architectures of AGV (Automated Guided Vehicle) systems

Conventional Research of Autonomous Distributed AGV



The machines generate an attraction field to obtain products.
On the other hand, AGVs transporting products sense the attraction fields and move to the machines.
Production proceeds due to such spatial–local interaction.

Reinforcement learning approach to self-organization in a biological manufacturing system framework, K Ueda, Proceedings of the Institution of Mechanical Engineers, Part B,Journal of Engineering Manufacture June 1, 2004 vol. 218 no. 6667-673

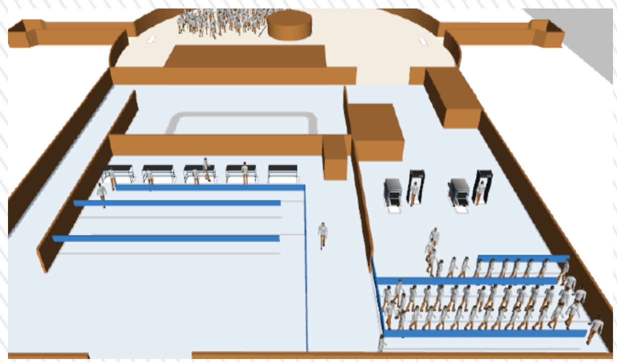
Objectives

- ✓ The **Social Force Model** is applied to the **autonomous distributed AGV** in order to analyze motion of them and to improve the efficiency of transportation process.
- ✓ Decision rules are proposed for input scheduling of materials to the manufacturing systems and avoidance of collision among AGVs in order to minimize total tardiness of products
- ✓ Simulation model is constructed based on the **Social Force Model** by using multi method simulator **AnyLogic**

Social Force Model

The Social Force Model is introduced to represent physical interactions and congestions among the people and the environment

Railway station



Airport

Shopping center

AnyLogic Pedestrian Library is based on Social Force algorithm. It is dedicated to simulate pedestrian flows in shopping center, airport, railway station and so on.

Formulation of Social Force Model

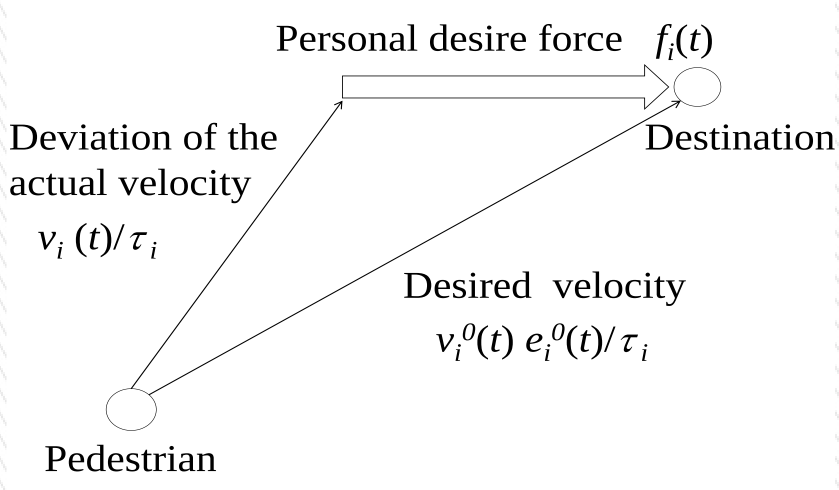
Helbing, Farkas and Vicsek (2000) has proposed a Social Force Model, where motives and impacts to a crowd of a pedestrian are represented by a combination of physical and psychological forces.

$$m_i \frac{d\boldsymbol{v}_i}{dt} = m_i \frac{v_i^0(t)\boldsymbol{e}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \boldsymbol{f}_{ij} + \sum_W \boldsymbol{f}_{iW} \qquad (1)$$

① ② ③

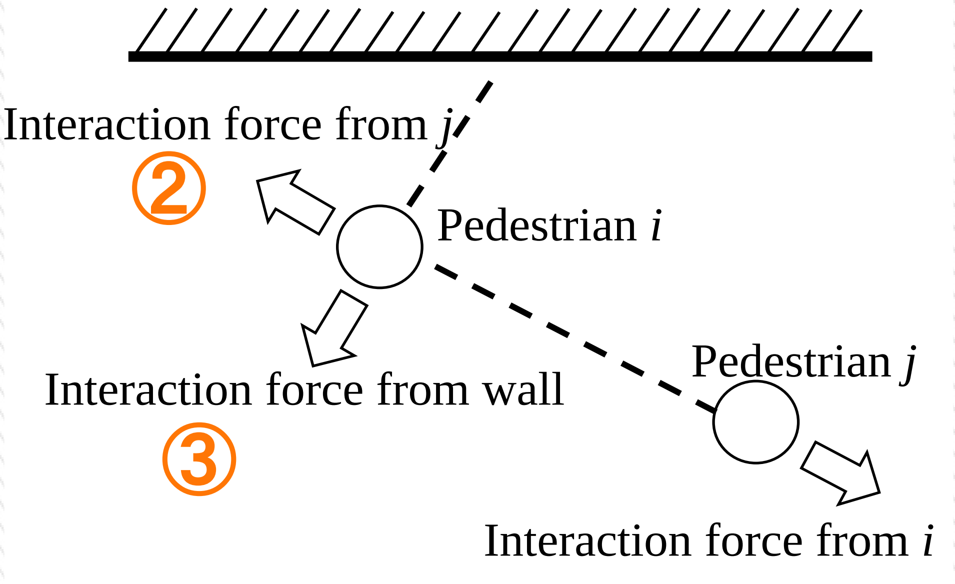
Equation (1) depicts the formulation of changing velocity at time t where a pedestrian's behavior is determined by his desired speed $\boldsymbol{v}_i^0(t)$ and direction $e_i^0(t)$ as well as interactions with other individuals and obstacles.

Term ① represents the personal desire force $f_i(t)$ obtained by deviation of the actual velocity and the desired velocity



Formulation of Social Force Model

The terms ② and ③ illustrate interaction forces from other pedestrians and the walls, respectively.



The interaction force consists of a psychological force resulting from distance between each other, and a physical force inspired by counteracting body compression and sliding friction.
The total force exerted by pedestrian *j* to pedestrian *i* is calculated as equation (2).

$$\boldsymbol{f}_{ij}^{psy} = A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i}\right)\boldsymbol{n}_{ij}$$

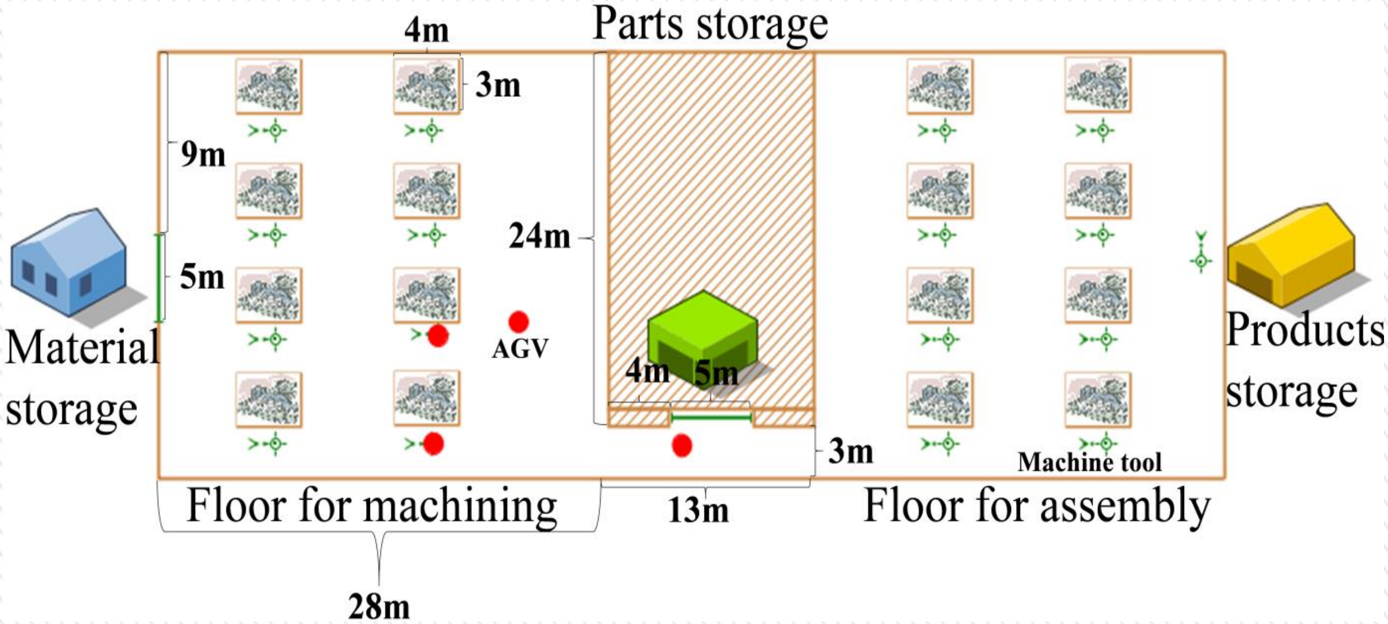
psychological force

$$\boldsymbol{f}_{ij}^{phy} = kg(r_{ij} - d_{ij})\boldsymbol{n}_{ij} + \kappa g(r_{ij} - d_{ij})\Delta v_{ji}^{t}\boldsymbol{t}_{ij}$$

physical force

$$\boldsymbol{f}_{ij} = \boldsymbol{f}_{ij}^{psy} + \boldsymbol{f}_{ij}^{phy} \qquad (2)$$

Target manufacturing system for autonomous distributed AGV system



- ✓ The AGVs are requested by the material storage to transport the materials to individual machine tools in the machining floor. The AGVs in the machining floor transport the materials which have been finished their machining processes to the parts storage, and return to the materials storage.
- ✓ The AGVs in the assembly floor are requested by parts storage to transport parts to the individual assembly machines. The AGVs in the assembly floor transport the parts which have been finished their assembly processes to the products storage, and return the parts storage.

Target manufacturing system for autonomous distributed AGV system

- AGVs

Speed: 25m/minute, Radius: 0.5m

- Machine tools

Operation time: 3minutes, Radius: 3m

Table　Materials input to manufacturing systems

Type of materials	Corresponding type of AGVs	Production volume	Due date	Average processing time
Material 1	AGV1	40	350	8.75
Material 2	AGV2	60	415	6.9
Material 3	AGV3	55	400	7.3
Material 4	AGV4	45	370	8.2

Decision rules for minimizing total tardiness

Decision rules are proposed for input scheduling of materials to the manufacturing systems and avoidance of collision among AGVs in order to minimize total tardiness of products. The material storage calculates ***$SLACK_1$*** given by Eq. 4 of individual materials to determine the input materials to the manufacturing systems.

$$SLACK_1 = DD - CT - (RPV \times APT) \quad (4)$$

where,

DD : Due date

CT : Current time

RPV : Volume of materials which have not been input to manufacturing system

APT : Average processing time

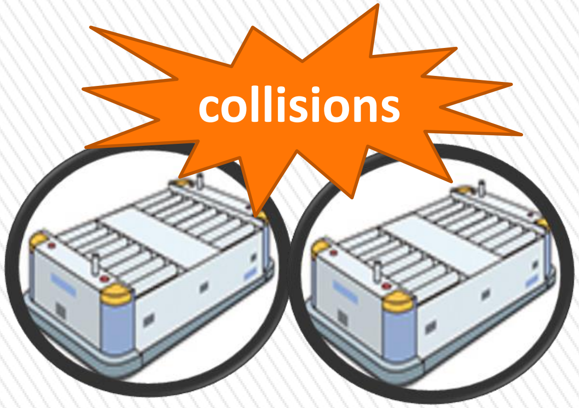
$$APT = DD / PV \quad (5)$$

where,

PV : Production volume of individual materials

Material storage requests AGV corresponding to material which has minimum ***$SLACK_1$*** to input the manufacturing system and to carry out transportation processes.

Decision rules for minimizing total tardiness



The collisions between two AGVs are occurred, if the center-to-censer distance of them is less than **2 times** radius of AGV.

One AGV will stop to avoid the collision if the center-to-center distance of AGVs is less than **1.2 meter** because the radius of AGV is set to **0.5 meter** AGVs calculate $SLACK_2$ given by Eq. 6.

$$SLACK_2 = DD - CT - RT - (RPV \times APT) \quad (6)$$

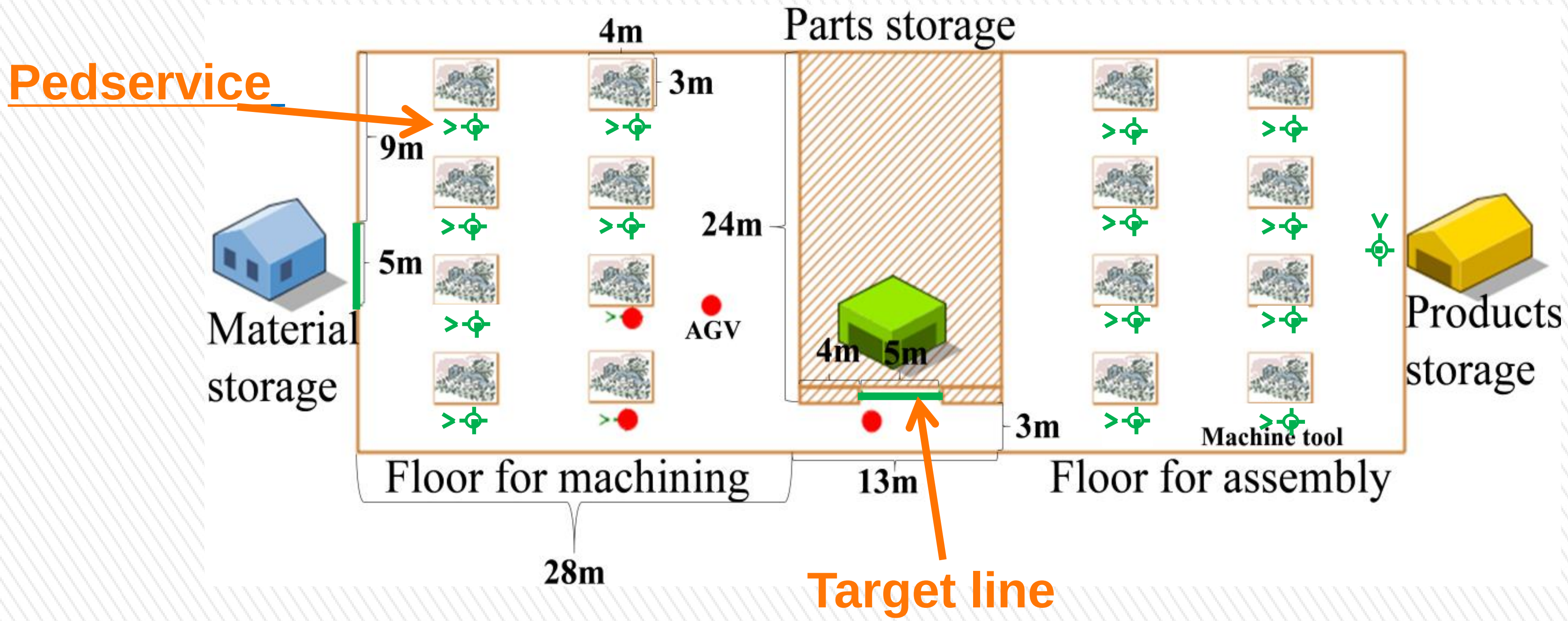
where,

DD : Due date

RT : Processing time of carrying job for remaining machining processes.

AGV which has maximum $SLACK_2$ will stop to avoid the collision in order to minimize the total tardiness of products.

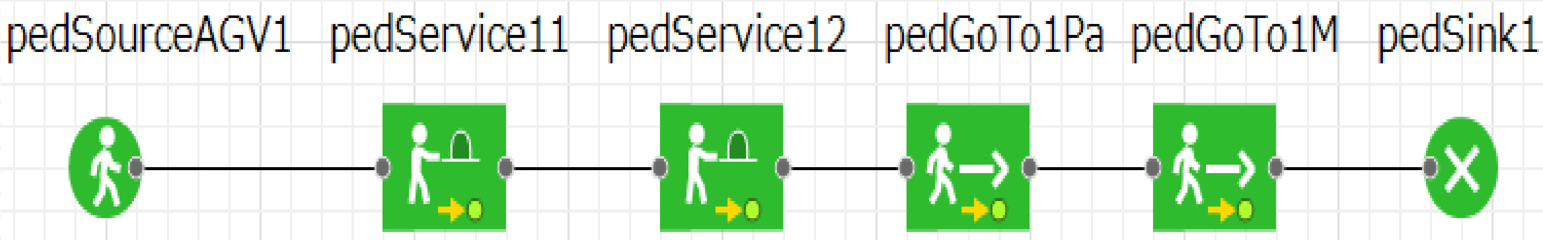
Application of Social Force Model to autonomous distributed AGV



Request of transportation processes for individual materials and parts are same as generations of the AGVs represented by the pedestrians in front of the materials storage and the parts storage.

Inject method is utilized to generate the AGVs in front of the materials storage based on the decision rule $SLACK_1$ and to generate the AGVs in front of the parts storage based on the time when AGVs are arrived from materials storage.

Application of Social Force Model to autonomous distributed AGV



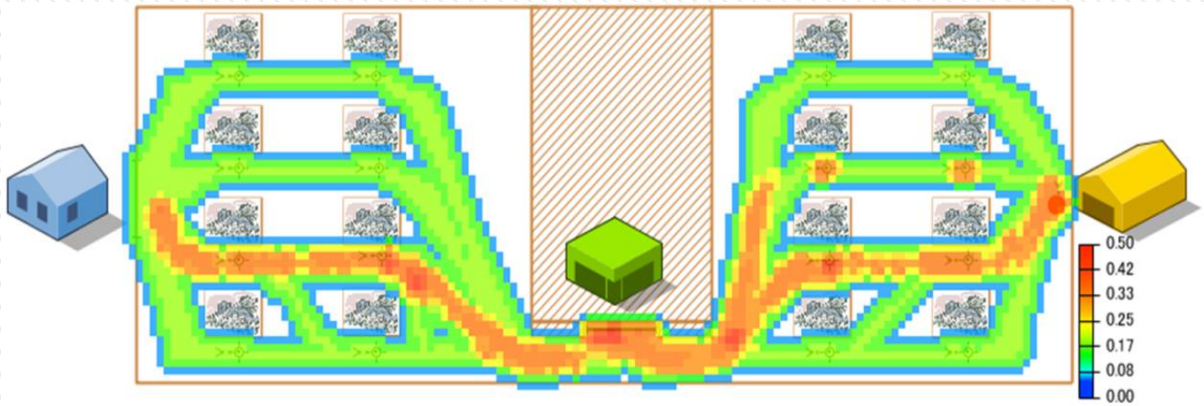
Example of flow chart of AGV1 represented by pedestrians

- AGV1 is generated by **pedSourceAGV1** and **inject method**
- **pedService11** and **pedSevice12** instruct AGV 1 to transport material 1 from material storage to machine tool 1 and machine tool 2 respectively. The material 1 transported by AGV 1 are also carried out the machining processes by machine tool 1 and machine tool 2 by instructions of **pedService11** and **pedService12**.
- **pedGoTo1Pa** instruct AGV1 to transport material which have finished machining processes to parts storage and put that in storage.
- AGV1 back to the material storage and be erased instructed by **pedGoTo1M** and **pedSink1**.

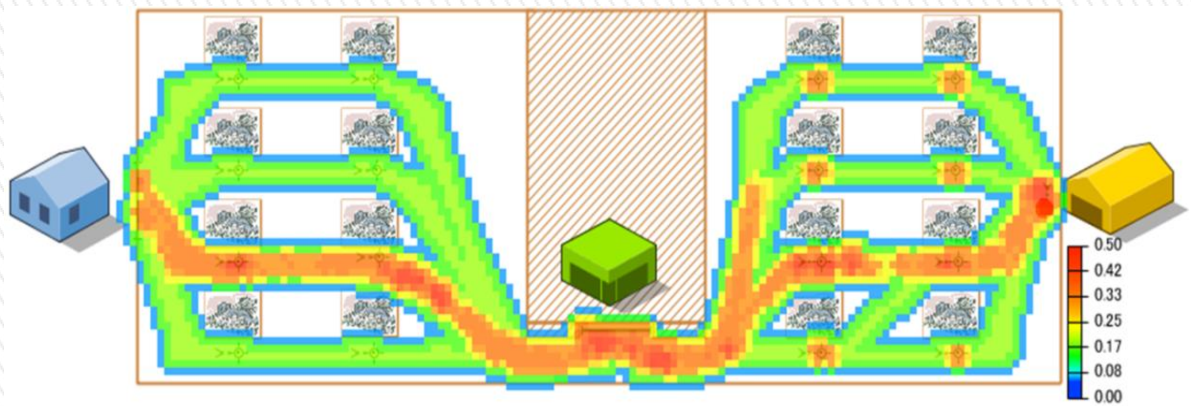
Simulation result for tardiness

Table Tardiness

	Material1	Material2	Material3	Material4	Total tardiness
Proposed method	21	2	5	16	44
Random method	23	3	9	19	54



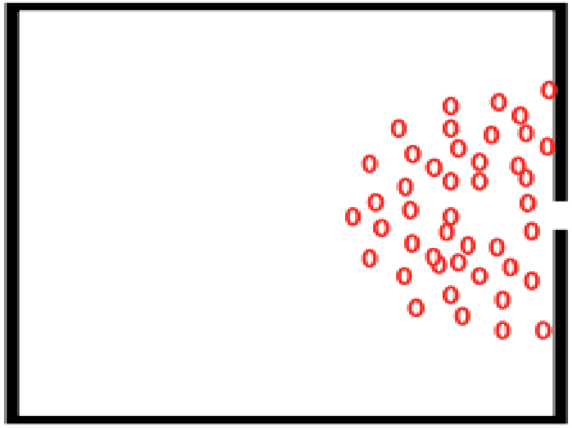
Case for less than or equal to 6 AGVs in each floor



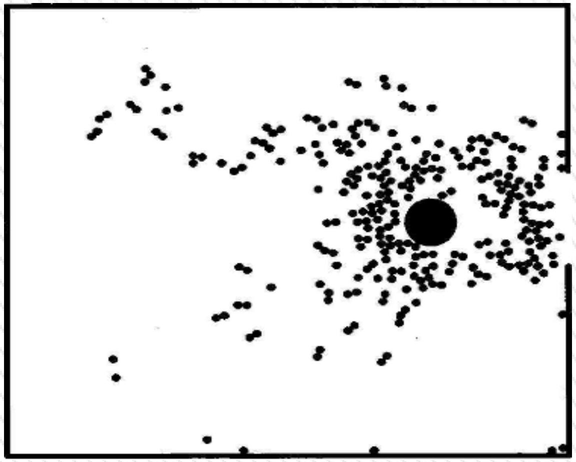
Case for less than or equal to 8 AGVs in each floor

Solution to clogging effect

The arching and clogging phenomenon

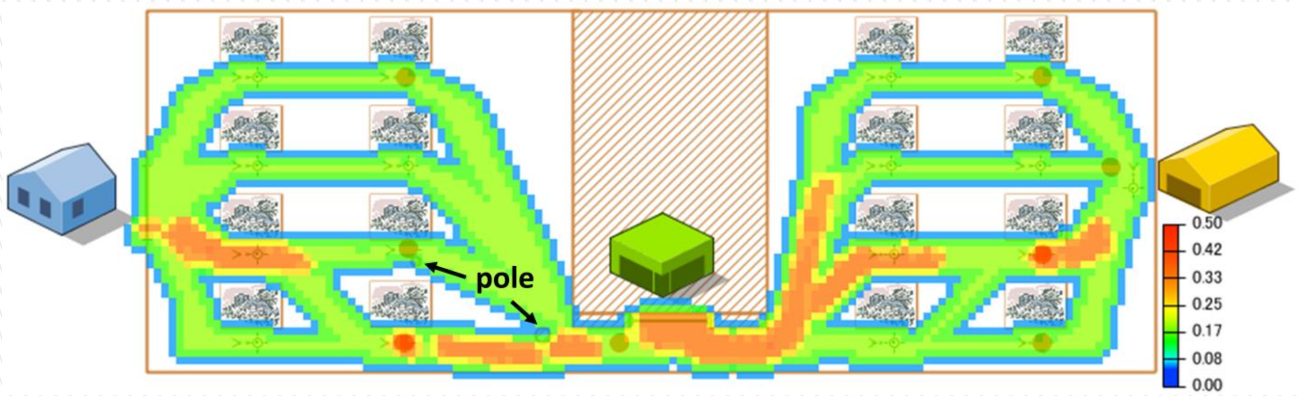


Solution of arching and clogging phenomenon by pole



D. Helbing, I. Farkas,P. Molnàr, Simulation of Pedestrian Crowds in Normal and Evacuation Situations, Pedestrian and Evacuation Dynamics ,Pages21-58,(2002).

Simulation result for setting pole



peddensity Map with setting of pole

Table Comparison results from models with and without pole

	Make-span	Number of stops
Without pole	457	32
With pole	448	21

Conclusions

- The Social Force Model is applied to the autonomous distributed AGV.
- Decision rules are proposed for input scheduling of materials to the manufacturing systems and avoidance of collision among AGVs in order to minimize total tardiness of products.
- The total tardiness of products are improved by using the proposed method. Make-span and number of stops of AGV are improved by setting poles.

Thank you very much
for your attention