Design Considerations for Automated Crane Assignment

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Abstract. This paper describes a method of multiple cranes assignment to operators who call cranes in a factory. Due to a crane moving on a rail, there is a restriction on the movement. Therefore, the crane cannot be delivered without proper assignment. To solve the cranes assignment problem, we propose two methods. The first is the optimal solution search method which finds the minimum travel distance combination from the number of cases that are derived by calculating the distance between all the cranes and all the operators. The second is the dynamic mapping method which finds the number of operators between each crane. Simulation results show that the dynamic mapping method sometimes performs the same assignment results as the optimal solution search method, but on average, the result of dynamic mapping method is farther than the optimal solution as the number of cranes increases. When partial regions are created by using the dynamic mapping method and an optimal solution search method is applied to each region, optimal solutions can be acquired while reducing the number of calculations.

1. Introduction
Factory machines have been developed with connectivity using industrial IoT technology [1]. The introduction of IoT will eventually lead to a complete automation of the factory. For example, forklifts and automated guided vehicles now are able to be autonomously operated [2]. Also, automation of cranes has been studied in consideration of moving stability [3,4]. At the current stage, the operator can use the controller to move the crane to an arbitrary position when using a crane in a factory. It is inconvenient because the operator must work with the controller and it may be dangerous because it moves together with using the controller. Proper assignment, a method to deliver a large number of cranes under the requisite operators may give operators benefits. Because the crane moves over rails, we must consider that a crane cannot cross a crane and rails beside it. In this paper, we introduce considerations for automated crane assignment and propose two methods. We also performed simulations using these methods and verified the assignment results.

Figure 1. (a)Physical picture and (b) schematics of automated crane system
2. Requirements of Automated Crane System
To properly assign a large number of cranes to operators, the requirements of HW specifications and some functions are described below.

2.1. Location awareness
To send a large number of cranes to the location of any operator, location information of cranes and operators is required. The position of the crane can be measured by the movement of the driving motor installed on the rail. The positions of operators and cranes are generally determined by wireless communication [5, 6].

2.2. Sensors
As for the method of grasping the position of the crane, an error occurs when there is physical interference in the factory or its location cannot be determined in real time. Large or great numbers of objects cannot be recognized by such location awareness, so additional sensors are required to check the presence of obstacles around the crane and their relative location for safe automated operation.

2.3. Communication module
The crane should be equipped with a communication module to exchange information with not only each crane and operator, but also the central control system. The communication module of the crane recommends a protocol that satisfies high reliability and real time communication. Also, pairing confirmation between controller and crane have to be satisfied some mandatory such as European standards (EN 60202-32).

2.4. Computing power
A micro controller unit (MCU) is installed in each crane to drive sensors and the communication module. Depending on the system’s specifications, location awareness and crane assignment are calculated by each crane. If the specifications of the MCU are low, it operates based on the information calculated by the central control system and sends the task report there. Operating a crane with low performance, if some crane problems occur during an automated operation, the whole operation is suspended until a decision is delivered by the central control system.

3. Assignment method
This chapter introduces two types of assignment problem solutions. In general, multi agent problem is solved by Munkres Assignment Algorithm to find an optimal assignment [7]. However, Munkres Assignment Algorithm can be applies to a given N x N matrix, which means the number of operators and cranes must be the same. To simplify the calculation, the distance between the operator and crane is calculated using only the x-axis length.

3.1. Method of Optimal solution search
First of all, calculate the distance between all the cranes and operators and fill in the table shown in Figure 2. The order of operators and cranes written on the table are sorted by distance to origin, respectively. Then, the number of cases where a crane is assigned to each operator is calculated. Considering that the cranes cannot cross the lateral cranes, for example, if crane 1 is assigned operator 2, other cranes cannot be assigned operator 1. Therefore, the number of cases is smaller than common combination problem. Finally, the combination that satisfies the minimum distance from the number of cases is the optimal solution.

Figure 3 shows cases that contain an optimal solution depending on the number of cranes and operators. As the number of cranes increases, the number of cases will increase. Moreover, when the number of operators is half the number of cranes, the number of cases becomes the largest.
3.2. Method of Dynamic mapping

The dynamic mapping method assigns cranes by using how many operators are placed between each crane. Figure 4 shows how to derive a solution using the dynamic mapping method. First, all cranes and operators are rearranged according to the x-axis of the coordinates. Then, some areas are created between cranes, and the operators in each area are determined. If some operators are placed on the right side of the rightmost crane, those operators are assigned to the rightmost crane. After that process, there are no operators placed on the right side of the rightmost crane. Next step, method finds some areas where two or more operators are placed. If so, a nearby crane moves in a virtual manner so that no one operator exceeds one area. Finally, the right-hand crane is assigned to each operator. In the case of problem shown in Figure 4, the result of allocations are crane2→operator1, crane3→operator2, crane4→operator3 and crane5→operator4.

One of the advantage of this method, it can solve assignment problem with relatively few calculations. This method is not a method for deriving an optimal solution.

4. Simulation results

4.1. Simulation Scenarios

To verify the validity of both methods, we use MATLAB to perform the simulation scenario described below:

- The area of the factory is 100 x 100 m.
- Two operators request the cranes simultaneously.
- When two cranes reach the operators’ locations, two other operators are randomly generated and request the cranes simultaneously.
The operator positions used in both methods are the same.
The above scenario is repeated 10 times and the sum of the travel distance about all cranes is calculated.
The number of operators was varied from three to eight, and each simulation was executed 10 times to obtain its average sum of travel distance and standard deviation.

4.2. Results
Figure 6 shows the sum of travel distance results from the crane calls. The larger the number of cranes, the smaller the total distance that all cranes move. The results of optimal solution search method present the shortest traveling distances under given conditions. The result of dynamic mapping method is farther than the optimal solution as the number of cranes increases. On the other hand, assignment solution of dynamic mapping method also performs that all cranes travel without collision of cranes in the iterative simulation.

Figure 5. Simulation image
Figure 6. Simulation results
Figure 7. Concept of Partial search method

Figure 7 shows the method of applying the dynamic mapping method to find the position of the operator and then applying the optimal solution search method in each part. For example, the optimal solution is found from the number of 16 cases when 6 cranes and 4 operators are placed in factory. If dynamic mapping method divides operators and cranes into two parts like group A(4 cranes and 3 operators) and group B(2 cranes and 1 operator), each parts has the numbers of 4 and 1 cases, respectively. In that example, this combination of methods lead to reduce the calculation to find optimal solution. However, this combination use method cannot always be solved with few calculations. For example, if there are three operators between one crane and another crane, the crane to be used in the calculation is added to both cranes and two more on each side, so that a maximum of six cranes are covered. In this case, the combination of methods has no effect of reducing the calculation amount. When the larger the number of cranes than the number of operators, this combination of methods presents faster result than only applied to optimal solution search method.

5. Conclusions
We introduce two methods of assigning cranes to operators in a factory, taking into account the limit of movement of the crane. When designing an automation system, it can be calculated by using optimal solution search method if it is operated by a central control system, and it can be operated by transmitting an allocation position to each crane. Also, if it is possible to simulate and allocate by itself in each crane, dynamic mapping can be applied to reduce the number of calculations.

Acknowledgments
This research was financially supported by the Ministry of Trade, Industry and Energy(MOTIE) and Korea Institute for Advancement of Technology(KIAT) through the International Cooperative R&D program(N0002620) and has been achieved in the European ITEA project “Optimised Industrial IoT and Distributed Control Platform for Manufacturing and Material Handling (OPTIMUM)
References
[1] Malte Brettel, Niklas Friederichsen, Michael Keller and Marius Rosenberg 2014 *International Journal of Information and Communication Engineering* 8(1) 37-44
[2] L. Li, Y. H. Liu, M. Fang, Z. Zheng and H. Tang 2015 *IEEE International Conference on Automation Science and Engineering (CASE)* 264-265
[3] A. Broad, J. Schultz, M. Derry, T. Murphey and B. Argall 2017 *IEEE Robotics and Automation Letters* 2(1) 239-246
[4] Oliver Sawodny, Harald Aschemann and Stephan Lahresc 2002 *Control Engineering Practice* 10 1323-1338
[5] Kyungsu Yun, Ji Kyu Park, Jae Young Ahn and Jae Kyun Kwon 2018 *ETRI Journal* 40(1) 101-110
[6] K. J. Flattery, B. Henry, M. Muadi, K. Walters, A. Eroglu and J. Rickman 2016 *IEEE/ACES International Conference on Wireless Information Technology and Systems (ICWITS) and Applied Computational Electromagnetics (ACES)* 1-2
[7] Margaretha Gansterer and Richard F. Hartl 2018 *European Journal of Operational Research* 1-12