TERRAIN ANALYSIS OF CROSS COUNTRY MOVEMENT FOR PATHFINDING OF COMBAT MOBILITY IN MILITARY OPERATIONS

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Abstract: Terrain analysis is important work for military war planning. The task is usually done by experienced personnel, however, applications of geoinformatics technology to support the efficient working process is still lacking. Some applications of this kind are reported in this paper whose objectives were to create CCM Maps for combat mobility using reclassified GIS data and develop application of suitable path finding to combat mobility in military operations based on shortest and fastest paths. The area of Maesot District, Tak Province was selected as a case study. The research began with the data collection, and GIS database construction, construction of the CCM maps, application of the Breadth First Search (BFS) and A-Star Search, and select the superior searching method and development of the automatic searching system. Results of the research show that A-Star search algorithm performed better than Breadth First Search. As a result, the A-Star was chosen to construct automatic path searching system called “CCM4CM”.

INTRODUCTION

One of the crucial tasks related to the terrain analysis is to find proper routes for the off-road movement of military personals and vehicles, called the “Cross-Country Movement” (CCM), based on the derived CCM map of the area. The CCM map is sometimes referred to as an avenue of approach map because it provides the best routes by which the vehicles can get to an objective when they cannot use prepared roads. It also shows parts of the terrain that these vehicles cannot cross which are important for the planning of military operations especially the offensive strategy.

Typically, the entire process of finding suitable paths for the combat mobility (from source to destination) was done by military experts based on prior knowledge of the key terrain and environmental characteristics of the operating area. The crucial ones are soil properties, types of dominant vegetation cover, surface configuration, and surface roughness (US Army, 1990). However, this is usually a rather time consuming process as most working steps have to be done manually. Therefore, it is normally a very exhausted working process when being applied to vast and complex topography. In those circumstances, some analyzing tools to assist this kind of work are critically needed. At present, such tools can be produced very effectively by using the computer-based geographic information system (GIS) as a core component. Examples of their developments and fruitful applications to the CCM mapping and path finding analysis for the assumed military operations are shown in this study. In the path finding part, two popular searching algorithms, Breadth First Search (BFS) and A-Star (A*) Search were considered in details.

In this work, the GIS-based models have been constructed and implemented to generate the preferred CCM maps and evaluate proper CCM paths for some specified army vehicles (under given requirements) in Maesot District, Tak Province. This area situates close to Thailand-Myanmar border and being considered as an important strategic location under supervision of the 3rd Army Area due to the still territory conflicts with Myanmar and the militarily operations of some ethnic minorities residing within the Myanmar border. Moreover, as a main gateway between Thailand and Myanmar, the district has gained notorious reputation for being center of the black market services like labor or drug trafficking which cause a new threaten problem to the country.The highly complex and difficult landscape of the area can lead to an exhausted terrain analysis carried out by the responsible agency. As a result, the proposed GIS-based models in this study might be a valuable tool to assist its work in the future.

Broad scope of GIS applications in military work is reviewed in Wilson and Gallant (2000), Satyanarayana and Yogandron (2012), Baijal, Arora and Ghosh (2012).

RESEARCH METHODOLOGY

There are three main steps that were fulfilled in this research:

1. Generation of the CCM map;
2. Conducting path finding analysis based on the BFS and A-Star algorithms;
3. Construction of the automatic path finding system.

In Step 1, the CCM map was produced based on the standard method of the US Army's manual on terrain analysis described in US Army (1990). On the CCM map, the approximated velocity (V) of each considered vehicle or troop unit was calculated grid-by-grid using the following formula:

$$V\ (\text{kph}) \;=\; F1 \times F2 \times F3 \times F4_{D/W} \times F5. \tag{1}$$

Terms F1 to F5 represent the key terrain and environmental characteristics of the area that can influence speeds of the travelling vehicles or troops as follows:

(1) F1 is slope factor as it determines the extent that any slope will deteriorate the vehicle's speed without consideration for any other physical factor;
(2) F2 is slope-intercept-frequency (SIF) factor. SIF is the number of times the ground surface changes between positive and negative slopes over a 1km distance;
(3) F3 is vegetation factor that determine impact of the vegetation density and distributing pattern on the mobility of vehicle's movement;
(4) F4 is soil factor that informs impact of the soil characteristics on vehicle's mobility. The analysis is normally separated into wet (W) and dry (D) conditions; and
(5) F5 is surface roughness factor that depends on the surface materials.

The F2-F5 factors have been typically set to have values between 0-1 only. The CCM mapping results are reported separately for each studied combat unit in both dry (D) and wet (W) seasons. More information of the F1-F5 calculation in given in Table 1 while the CCM map classification system is shown in Table 2.

There were 6 types of the military combat units being considered in this work (represented by their chosen troop unit or main used vehicle): (1) Standard infantry (Foot troops), (2) Armored infantry (M113), (3) Mechanized infantry (M35 truck (2½ Ton)), (4) Tank cavalry (Stingray Light Tank), (5) Armored cavalry (M113), and (6) Reconnaissance cavalry (Scorpion Tank).

In Step 2, the path finding analysis based on the BFS and A-Star algorithms was conducted in 24 cases (12 for shortest path finding and 12 for the fastest path finding) and the results were then compared in terms of 4 main criteria which are: (1) Completeness; (2) Space complexity; (3) Time complexity; and (4) Optimality. More details of each index are given in Table 3. Main difference between the two chosen algorithms lies in their searching processes. BFS is the so-called uninformed search and, as the name implies, it searches tree structure from the initial state breadth-wise, level by level. In the process, it shall explore all states in one level before jumping to the next level. Once the solution is found the search process stops. All these tasks are done without prior information of the possible right solution.

On the contrary, the A-Star search is prime example of the so-called informed search. Instead of looking at the distance from the starting node, A-star will choose nodes based on the estimated distance from the start to the finish. The estimate is formed by adding the known distance from start to a guess of the distance to the goal. The guess, called heuristic, shall improve efficiency of the A-Star relative to BFS and helps it works faster than the BFS in general (Jones, 2008).

In Step 3, the superior searching algorithm found in Step 2 (BFS or A-Star) was applied to develop automatic path finding program called "CCM4CM" operating system. To achieve this, the database system was established by the Microsoft Access 2007 and user interface was utilized with Microsoft Visual Basic 2010. Main outputs of the system are the preferred paths (shortest or fastest condition) over a given CCM map of the interested are

Table 1: Description of the formulas used to calculate F1F5 factors in Eq. 1.

Factor	Formula	Note
F1	$F1\,(kph) = \dfrac{\text{Max off- road gradability (\%)} - \text{Surface slope (\%)}}{\text{Max on- road gradability (\%)}}$ x Max road speed (kph); Max = maximum,	If F1 $\leq$ 0, F1 = 0 (No Go).
F2	$F2 = (-0.0008888)\,[slope] + 1$	–
F3	$F3 = V_R \text{ x } \max(V_1, V_2)$; $V_1 = V_F \text{ x } V_C$; $V_C = \dfrac{SS - SD}{W}$, $V_2 = 1 - \left[V_T \text{ x } \dfrac{SD^2}{OD^2}\right]$; $V_T = \dfrac{(W + SD)}{SS}$, V_R = Vegetation roughness factor, V_F = Vehicle factor, W = Vehicle width (m), SS = Stem spacing (m), SD = Stem Diameter (m), OD = Override diameter of the vehicle.	1. If $V_1 \leq 0$, $V_1 = 0$, 2. If $V_1 \geq 1$, $V_1 = 1$, 3. If F3 $\geq$ 1, F3 = 1, 4. If F3 $\leq$ 0, F3 = 0 (No Go), 5. If values of SS/SD are not available, F3 = V_R.
F4	$F4_{D/W} = \dfrac{RCI_{D/W} - VCI_1}{VCI_{50} - VCI_1}$; RCI_D = RCI value for dry condition, RCI_W = RCI value for wet condition, VCI_1 = Vehicle cone index (1 pass), VCI_{50} = Vehicle cone index (50 pass).	1. If F4 $\leq$ 0, F4 = 0 (No Go), 2. If F4 $\geq$ 1, F4 = 1.
F5	F5 = Surface roughness factor (0 - 1)	–

Table 2: Category for speeds and their associated CCM map unit.

Speeds (kph)	Basic descriptor	CCM Map Unit
> 30	Go	Go
> 15 – 30	Restricted Go	Slow Go
> 5 – 15	Slow Go	Slow Go
> 1.5 – 5	Very Slow Go	Slow Go
$\leq$ 1.5	No Go	No Go
–	No Go (Open water)	No Go
–	No Go (Built-up area)	No Go

Table 3: Performance criteria for the BFS and A* search algorithms.

Performance criteria	Details
1. Completeness	Ability to find its specific solution if one exists.
2. Space complexity	Amount of the memory in use (to find solution).
3. Time complexity	Amount of the processing time in use (to find solution).
4. Optimality	Ability to find the right solution of interest (shortest/fastest path).

Table 4: The covering area of three trafficability classes: Go, Slow Go, No Go.

Trafficability class	Covering area (%)									
	Infantry troop		M113		M35		Stingray		Scorpion	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Go	98.98	96.96	6.29	5.02	2.32	2.16	16.48	3.31	18.18	11.04
Slow Go	–	–	31.99	31.60	33.16	16.61	21.19	22.33	19.99	25.76
No Go	1.02	3.04	61.72	63.38	64.52	81.23	62.33	74.36	61.83	63.20

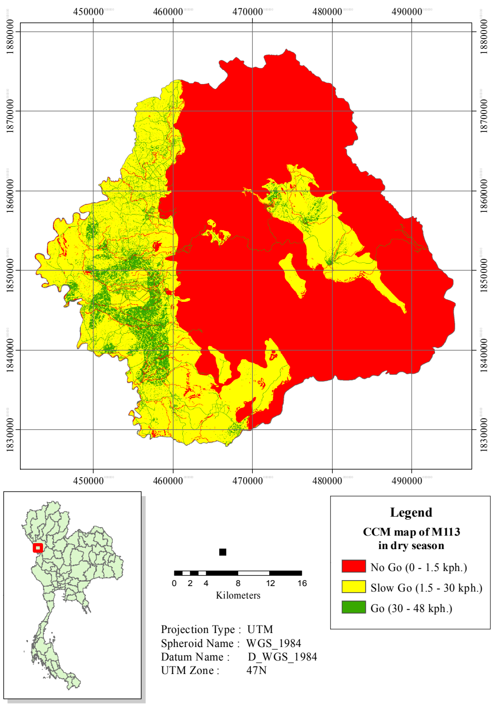
RESULTS AND DISCUSSION

In Step 1, From CCM maps prepared for each chosen troop unit/vehicle type mentioned earlier (foot troop, M113, M35, Stingray and Scorpion) (see Figures 1-2 for examples of the CCM maps), their trafficability in the study area is reported in Table 4 with 3 classes identified: No Go (0-1.5 km/hr), Slow Go (1.5-30 km/hr), Go (> 30 km/hr).

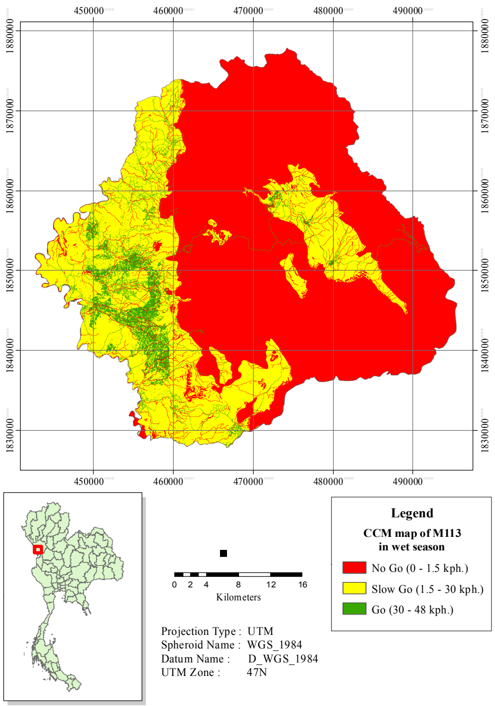
For the standard infantry (foot troops), they can move pass most terrains well in both dry and wet seasons except over the few specified No Go areas (water body). The standard velocities of the movement are 4 km/hr during daytime and 2 km/hr during nighttime, respectively. For the Armored infantry/cavalry (M113)**,** their Go areas were mainly found on the western side of the district due to the rather flat terrain of the area that is suitable for the CCM movement, e.g. area with surface slope of 0-3% (Figure 1). On the contrary, the No Go areas notably situate within the mountainous region in the middle and eastern parts due to the high surface slope and the proneness to landsliding of the areas. In addition, the Slow Go areas were found distributing in-between the Go and No Go areas. The M113's CCM maps look very similar in both wet and dry seasons with area of about 5-6% for the Go, 31-32% for the Slow Go, and 61-63% for the No Go. For Mechanized infantry (M35 trucks), pattern of their CCM map in dry season is rather similar to that of the M113 map with Go area at about 2.32%, Slow Go area about 33.16% and No Go area about 64.52%. However, the Slow Go area is dropped significantly to about 16.61% in wet season while the No Go area is increased to be 81.23%. This indicates the trafficability of M35 is quite limited in the wet season.

For Tank cavalry (Stingray tank) , their GO area in dry season is notably higher than those of the M113 and M35 (about 16.48%) while Slow Go drops to be about 21.19% and the No Go maintains at about 62.33%. However, the Go area is sharply lost to be at 3.31% only in wet season while the Slow Go area is slightly increased to be about 22.33% and the No Go area is arisen to be at about 74.36%. For Reconnaissance cavalry (Scorpion tank), GO, Slow Go, and No Go areas in dry season are comparable to those of the Stingray tank (about 18.18%, 19.99, and 61.83% respectively). However, the Go area is considerably reduced to be at 11.04% in wet season (Figure 2).

In conclusion for all considered vehicles, their Go areas dominate on the western side due to the relatively flat terrain. On the contrary, the No Go areas situate mainly within the mountainous region in the middle and eastern parts. In addition, the Slow Go areas were usually found distributing in-between the Go and No Go areas.

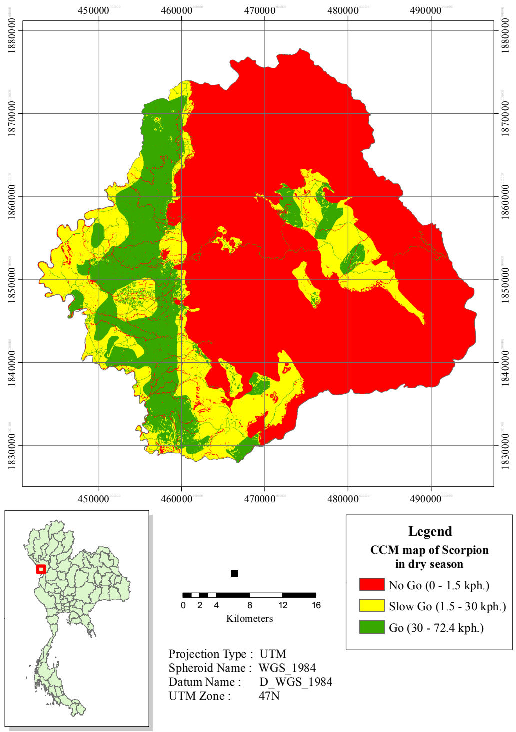


(a) Dry season (M113)

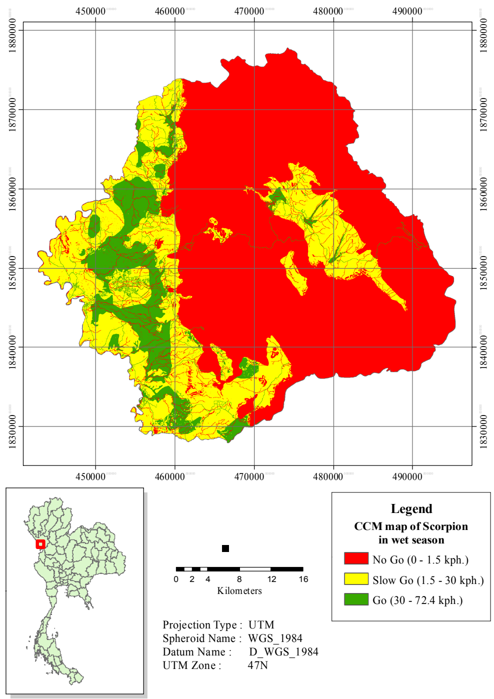


(b) Wet season (M113)

Figure 1: CCM map for the armored infantry/cavalry (M113) in dry and wet season.



(a) Dry season (Scorpion)



(b) Wet season (Scorpion)

Figure 2: CCM map for the reconnaissance cavalry (Scorpion) in dry and wet season.

Table 4: Results of the path finding analysis (fastest path) of the BFS and A* search algorithm.

Case	Infantry unit	Case	Infantry unit
1	Standard infantry (foot troop) (day, dry)	7	Tank cavalry (Stingray) (dry)
2	Standard infantry (foot troop)(night, wet)	8	Tank cavalry (Stingray) (wet)
3	Armored infantry (M113)(dry)	9	Armored cavalry (M113) (dry)
4	Armored infantry (M113) (wet)	10	Armored cavalry (M113) (wet)
5	Mechanized infantry (M35) (dry)	11	Reconnaissance cavalry(Scorpion) (dry)
6	Mechanized infantry (M35) (wet)	12	Reconnaissance cavalry (Scorpion) (wet)

Table 5: Performance comparison for the BFS and A* search algorithms.

Performance criteria	Performance comparison	
	BFS	A*
1. Completeness	Yes	Yes
2. Space complexity	Uncertain	Uncertain
3. Time complexity	Always worse	Always better
4. Optimality	Always worse	Always better

In Step 2, efficiency in path finding analysis of the two chosen algorithms (BFS and A-Star) was assessed. To achieve this task, twelve path finding cases were evaluated with the shortest and fastest preferences where two cases each (dry/wet season) were proposed for each troop unit and the concerned vehicle type (24 cases in total) (Table 4). Some obtained results are reported in Figure 4 and the overall conclusion is summarized in Table 5.

From Tables 5, it can be primarily concluded here that for all four performance criteria stated in Table 3, both algorithms can find the solutions under their own procedures (but not exactly the same one). However, the A-Star did considerably better than the BFS in terms of processing time and right solution found in all cases under consideration (especially the processing time). But in terms of the used memory, one's superiority is still uncertain.

In Step 3, the A-Star algorithm was chosen to construct automatic path searching system. To employ the system, users must access through the accessing interface where the valid account and password are needed and the output interface that gives users opportunities to select initial conditions of the processing of interest (Figure 4), for examples, type of preferred route (shortest/fastest), type of combat unit, time (day/night), season (dry/wet), start/end positions. Results of the processing will be reported as continuous lines on map and specific details of the identified routes given in text, e.g. total length, travelling time (Figure 5).

The system is able to search for the preferred shortest/fastest routes under given specific pair of the start and end points where two types of searching priorities are available:

(1) Normal search-no extra requirements of the preferred solution needed in the analysis; and
(2) Conditional search-some specific conditions are required for path finding analysis. These are:
    (a) The preferred path must, or must not, pass some specific locations along the route
    (b) The preferred path must not pass close to some locations along the route at some certain distances;
    (c) The preferred path must, or must not, pass over some specific areas along the route; and
    (d) The preferred path must pass the instantly-built bridge along the route.

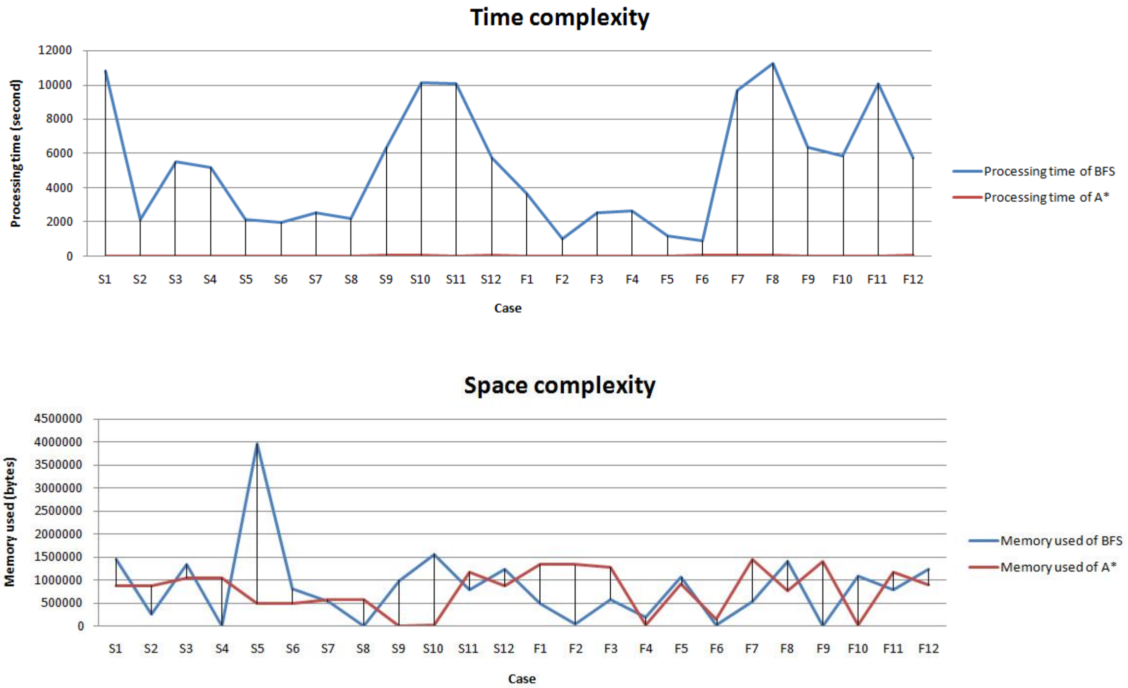


Figure 3: Efficiency comparison between the two methods in terms of time and space complexities.

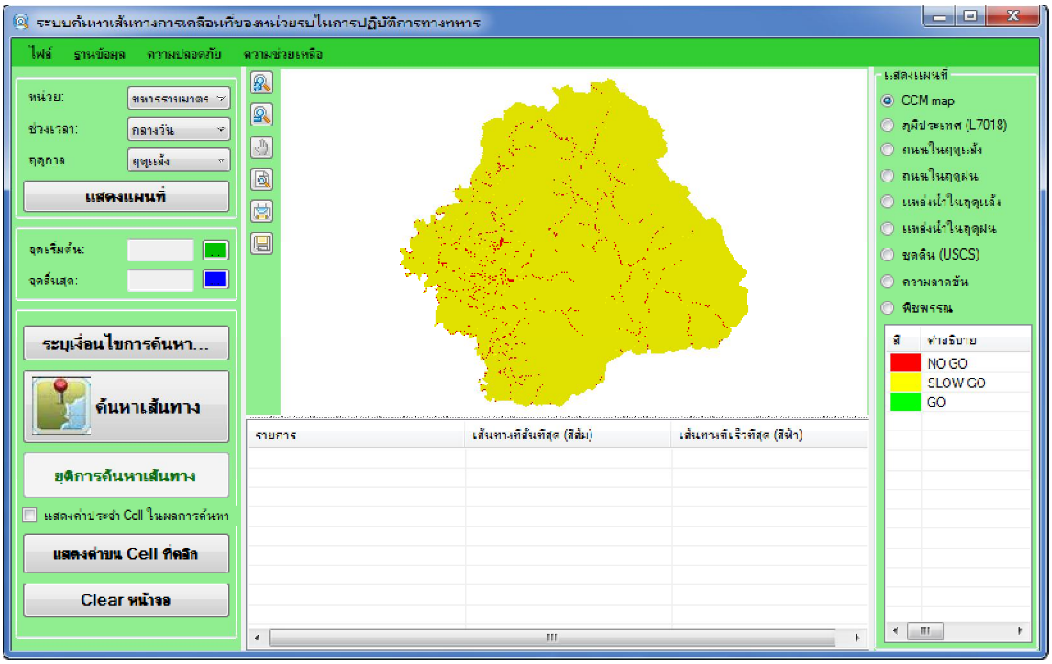


Figure 4: The main graphic user interface of the CCM4CM system.

Figure 5: Example of resulted report of the normal search system (shortest path in orange and fastest path in blue).

CONCLUSIONS

In this study, in the first part, the GIS has been applied to construct the CCM map for the chosen troop unit and vehicle types based on the standard procedure of the US Army. It was found that, for all considered vehicles, their Go areas dominate on the western side of the study area due to the relatively flat terrain. On the contrary, the No Go areas locate mainly within the mountainous region in the middle and eastern parts. In addition, the Slow Go areas were usually found distributing in-between the Go and No Go areas. In part two, the A-Star algorithm was found to be superior to the BFS (regarding to all 24 test cases), especially, in terms of the optimal solution and the processing time. As a consequence, the A-Star was chosen to construct automatic path searching system called "CCM4CM".

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