Modified Extended Conflict Based Search Algorithm for Convoy Movement Problem

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Abstract—*This paper presents an improved method for addressing the convoy movement problem of minimizing conflicts, using a modified extended conflict based search algorithm. The extended conflict based search algorithm was developed to handle limitations associated with the standard conflict based search algorithm in terms of its ability to handle large test cases, without the constraints of memory or computational time. The* ***Extended Conflict Based Search Algorithm****, however, had the tendency of generating an optimal solution with a significant number of conflicts. The proposed algorithm was developed to solve the Convoy Movement Problem with large test cases and all the constraints involved while minimizing the number of conflicts generated. The proposed algorithm was developed using a meta-agent approach with a look-up table.* ***The developed method was implemented as a C# based graphical user interface. Its performance is evaluated using*** *sensitivity analysis and the results are* ***compared with results obtained using Extended Conflict Based Search Algorithm.*** *Results obtained show a higher sensitivity analysis values for the small network sizes and lower sensitivity analysis values for large network sizes. The mXCBS algorithm produced a sensitivity improvement of 42.85% over XCBS for small network sizes and 35.14% improvement for large network sizes. The results of this work showed that the output accuracy of mXCBS is robust to both small and large network sizes irrespective of number of convoys and constraints involved compared to the XCBS.*

Keywords—*XCBS algorithm, meta-agent approach, conflicts, sensitivity analysis*

I. Introduction

Military, humanitarian and other missions require the efficient movement of people and resources between locations [1]. In military deployments, units often move as a convoy of vehicles carrying personnel, equipment, ammunition, food stuff and other supplies [2]. Movement of military convoy is from head to tail which have a distance of about 50m-100m in between the vehicles and each particular convoy is allied with a source to final location pair in between, that it has to tour through a narrow route for the purpose of the task to be achieved ahead of them. [3]. The difficulty experienced in proficient planning of convoy movement from the source to destination nodes for the purpose of minimizing total arrival time taken by the convoys at their individual final location putting into consideration some certain constraints which include, no convoy stops on the way and it is prohibited for two or more convoys to surpass or cross each other on the same way with the smallest headway time kept constant is referred to as convoy movement problem (CMP)[2]. This is important, so that when two or more convoys journey along the same way in the same path, the road may not have adequate strength to contain them simultaneously. Consequently, a smallest headway has to be kept constant between them so as to prevent conflicts [4].

Several different approaches have been proposed in solving the CMP. These include the mixed integer programming formulations using a Tabu search-based approach [5], distributed approaches to the CMP using hybridization of conflict resolution through distributed constraint optimization and coalition formation [6], reservations on the time windows of convoy agents' network resources[7], application of genetic algorithm in combination with a discrete event simulation[4] and ant colony optimization (ACO) based approach in which optimal quality solution and computational time was achieved with lower number of ants [1]. Other approaches explored Convoy Movement Problem while taking care of constraint (such as convoy variable speed), though majority of them were not able to demonstrate optimal solutions that can handle. This led to the concept of the modified extended conflict based search (mXCBS) algorithm.

II. LITERATURE REVIEW

The XCBS has been used to solve the CMP and significant performances when compared with other algorithms have been observed. [8] considered the problem of convoy protection missions using a fixed-wing Unmanned Aerial Vehicle (UAV) in scenarios where the radius of the circular region of interest around the convoy was smaller than the UAV minimum turning radius. Using the Moving Path Following (MPF) method, they proposed a guidance algorithmic strategy where a UAV moving at constant ground speed was required to converge to and follow a desired geometric moving path that was attached to the convoy center. Conditions under which the proposed strategy solves the convoy problem are derived. A performance metric that was proposed together with numerical simulation results demonstrated the effectiveness of the approach used. [9] designed a distributed intelligent system for guiding the emergency convoys; a solution that will be based on a group of agents and on the analysis of traffic in order to generate collective functional response. It fits into the broader issue of Distributed Artificial System (DAI), which was to operate a cooperatively computer agent into multi-agents system (MAS). The article describes conceptually two fundamental questions of emergency convoys. The first question is dedicated to find a response to the traffic situation (i.e. fluid way), while the second is devoted to the convoy orientation; while putting the point on the distributed and cooperative resolution for the general problem. [10] accessed convoy movement problem using a bi-criteria model for the peacetime edition, with the aim of reducing the total time covered and journey period as the main aims. Goal programming and simulated annealing techniques were used in their work. [11] introduced a fundamental reinforcement learning (RL) model for determining convoy schedules and route clearance assignments in light of attack costs on a transportation network subject to IED ambushes. The model represents opponent interaction by assuming dependence between attack probabilities and targeted traffic patterns. There were currently few analytical approaches for this problem in the literature, but RL algorithms offer opportunities for meaningful improvements by optimizing individual movements across an extended planning horizon, accounting for downstream attacker-defender interaction. Therefore, this paper introduces the RL methodology with a fundamental formulation and initial computational results which show meaningful performance improvements over a one-step, myopic decision rules. However, their algorithm focused on obtaining a optimal solution to the modelled problem within a specific period of time that was realistic in the context of the problem, but could not handle large test data cases and could not detect conflict generated during the process of convoy movement. [3] proposed to form a convoy of vehicles autonomously following a given path. Particularly, the part of the complex mobile robot guidance system related to leader-follower control process was presented in detail. The ultimate objective was to use the local vision system of mobile robotic platform to follow the moving goal as accurate as possible simultaneously keeping the constant distance from the leading robot. Then, a proper controller design was proposed together with the implementation for the Amigobot mobile robotic platform from Adept Mobile Robots Inc. A verification of the guidance system performance via navigation experiments was also presented. [12] developed a new application of data mining method for examining of convoy vehicles based on automatic number plate recognition (ANPR) scheme. The amount of ANPR data taken daily by traffic cameras in the road network was very considerable. Data clustering method was used to remove important traffic patterns from the ANPR data to perceive and identify strange patterns and asymmetrical behaviour of multi-vehicle convoy activities, the results obtained in their work was quite encouraging which established the functionality and precision of the proposed algorithm. However, the data collected from traffic cameras installed at various road networks did not consider capturing the number of convoys at particular nodes and edges and the technique applied could not detect the number of conflicts generated. [13] proposed a velocity control technique for vehicle convoy. Their work focused on minimizing the speed fluctuation of the follower vehicles during the convoy movement. In order to conclude on the parameters and the summation of sensitivities for all the lead convoy vehicles which were maximized, a stability investigation of the models were carried out.The model was applied for the speed control of the vehicle robots in the vehicle platoon. Comparison of the result obtained from the experiment and numerical simulation was carried out in order to ascertain the legitimacy of the model. The result obtains from the experiment qualitatively aligned with the computer simulation. However, in their work, only the speed of the lead vehicle was considered but the size of convoy, node and vertices were not considered at all and the technique applied cannot detect the number of conflicts generated during convoy movement. [14] presented a computational complexity of some constrained classes of CMP. Their major aim was to recognize the frugal problem description that made the Convoy Movement Problem difficult. A polynomial-time technique was provided for solving the problem of single criterion two-convoy movement problem. The performance of simple prioritization-idling approximation technique was used for analyzing the K-convoy movement problem. However, in their work, zero-length convoys was considered without overtaking constraint on undirected graph and their technique could not detect the number of conflicts generated during convoy movement. [1] examined the effectiveness of ant colony optimization technique on the Convoy Movement Problem. The proposed version of the technique used, considered several ant colonies and consequences that were introduced while bringing up to date the path trailed as well as in the cost function anytime that there was a defiance of definite limitations. In the technique used, a different ant colony with exceptional pheromone accumulations was associated to individual convoy and accordingly the path of each individual colony was kept informed disregarding the pheromone path taken by other colonies. The results achieved were quite good for such instances. However, the technique used did not provide optimal result for problems of large network sizes in terms of computational time and quality of the solution.[2] studied the Convoy Movement Problem in peacetime from the perception of the civilians, with the aim of how to reduce civilian traffic disruptions. In their work, an exact hybrid technique was developed which comprises of the technique used for obtaining a minimum weighted *k*-clique in a *k*-partite graph and the k-shortest path technique. However, the convoy formulation problem, which determines the frequency and size of convoy movement was not considered by the technique, implying that the proposed technique cannot produce optimal solution for large network data in terms of the number of conflicts generated and computational time.[15] proposed an XCBS algorithm, which allowed optimal planning and scheduling for spatially extended objects. In their work, they demonstrated the technique used for Convoy Movement Problem using large test cases such as eight hundred convoys in road networks with forty thousand vertices and seventy-nine thousand, six hundred edges. Their algorithm was used for Convoy Movement Problem for vast road networks and large numbers of convoys in a distributed manner, but the central agent achieved the process of conflict detection. However, in their work, the XCBS Algorithm had to process a significant number of conflicts between agents when there was high rate of internal conflicts before it could obtain an optimal solution which in turn affected the solution time. The rest of the paper is organized as follows. Section 2 introduces the literature review of the CMP, while section 3 discusses the methodology adopted in carrying out the work. Also, section 4 displays the simulation results and discussion and finally, the conclusion and area for further work is presented in section.

III. METHODOLOGY

The steps of the methodology adopted in this work towards developing a modified extended conflict based search algorithm for CMP are summarised below:

a) Implementation of the existing extended conflict based search algorithm [15] for convoy movement problem. To develop the XCBS algorithm, the following steps are carried out:
   i) Initializing the convoy parameters which includes the number of convoys, vertices, edges, convoy length and convoy speed.
   ii) Define the root constraint tree (CT) node with optimal shortest plan for each agent.
   iii) Insert root to OPEN SET, while OPEN SET is not empty, explore CT node to obtain the minimum cost.
   iv) Validate plan until conflict occurs.
   v) Resolve Conflicts
b) Development of the modified extended conflict based search algorithm for convoy movement problem. To achieve this, the following steps were adopted:
   i) Steps (i-iv) were repeated.
   ii) Meta-agent technique was applied through the selection of the threshold values from the look-up table.
   iii) Resolve Conflicts
c) Comparison of the performance of the modified extended conflict based search algorithm with that of the extended conflict based search algorithm in terms of the number of conflicts generated using sensitivity analysis.

A. Initializing convoy parameter

The performance of XCBS depends on the appropriate selection of its control parameters (number of convoy, convoy length, convoy speed, number of edges, number of vertices and waiting interval time). The appropriate values selected for these parameters are presented in Table I.

TABLE I.
XCBS SYSTEM PARAMETERS [15]

S/N	Description	Symbol	Unit	Value
1	Convoy length	l_c	m	1-700
2	Number of convoy	N	-	20-800
3	Convoy speed	S_c	m/s	0-200
4	Number of edges	N_e	-	360-79,600
5	Number of vertices	N_v	-	100-40,000
6	Waiting internal time	t_w	s	3

The simulation parameters presented in Table I were selected because XCBS has been reported to perform optimally within this range of values.

To ensure efficient and improved optimal solution, the following model assumptions were made [2]:

a) The road network is represented by a directed graph G = (V, E), where V is a set of vertices or nodes and E is a set of edges or links.
b) Each convoy needs to be sent from an origin to a specific destination.

c) Convoys should not overtake each other on the same road.
d) Each convoy has a specified physical length which consists of the length of each vehicle and the safety gap between each vehicle inside the convoy.
e) Convoys can only wait at their origin for discretely defined time interval. Waiting is not permitted elsewhere.
f) Each convoy has an earliest departure time from its origin and a latest arrival time to its destination.
g) Two convoys cannot face each other when traversing in opposite direction of the same road.
h) The speed of each convoy on each road of the transportation network is constant and may vary from convoy to convoy and road to road.
i) Constraints assure that headway is maintained between two convoys which pass through the same node, such that two convoys do not occupy the same node at the same time.
j) After inter-convoy conflict has occurred, there is change of imposed waiting time interval between the convoys involved.
k) All the convoys must arrive at the destination before any of them can leave back to the source location.

B. Generating optimal shortest path for convoy agent

The Dijkstra's algorithm was used to find the optimal shortest paths for each convoy movement from their source location to their destination. For each convoy, a modified graph is being defined. In this graph, the length of each road is updated by the mathematical expression shown below:

$$\left(\frac{l_r + l_c}{S_c}\right) \times F_{tv} \quad 3.1$$

where:

l_r is the length of the road.

l_c is the length of the convoy.

S_c is the speed of the convoy on the road.

F_{tv} is the traffic volume of the road

C. Obtaining minimum cost function

The total time taken for each convoy agent to traverse its optimal shortest path is calculated using the mathematical expression in equation 3.2 as illustrated below:

$$Cost\ (P_j) = \sum_{n=1}^{q}\left[\frac{L_n}{\min(S_j, S_n)}\right] + \sum_{r=0}^{l} w_r + \sum_{r=0}^{m} h_r + \frac{L_j}{S_j} \quad 3.2$$

Where:

Cost (P_j) = Total time taken by convoy agent.

S_j = convoy speed

S_n = edge speed

L_j = convoy length

L_n = edge length

D. Road Network Modelling

The test data used in the modelling of the road network are randomly generated for the directed connected graphs using Fig. 1. In this case, the connectivity of the graph was guaranteed and tested by the Dijkstra's algorithm.

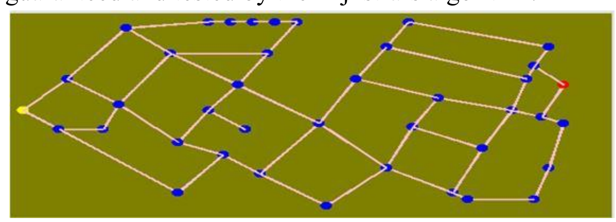

Fig. 1: Road Network Modelling

Tables II and III show the parameters used for small network sizes and large network sizes respectively as used in this work.

TABLE II.
PARAMETERS FOR SMALL NETWORK SIZES

S/N	Description	Symbol	Unit	Value
1	Convoy length	l_c	m	1-200
2	Number of convoy	N	-	20-100
3	Convoy speed	S_c	m/s	0-200
4	Number of edges	N_e	-	300-4900
5	Number of vertices	N_v	-	100-2500
6	Waiting internal time	t_w	s	3

TABLE III.
PARAMETERS FOR LARGE NETWORK SIZES

S/N	Description	Symbol	Unit	Value
1	Convoy length	l_c	m	200-700
2	Number of convoy	N	-	100-800
3	Convoy speed	S_c	m/s	0-200
4	Number of edges	N_e	-	19800-79,600
5	Number of vertices	N_v	-	10000-40,000
6	Waiting internal time	t_w	s	3

Fig.2 shows the flowchart of the mXCBS as shown below:

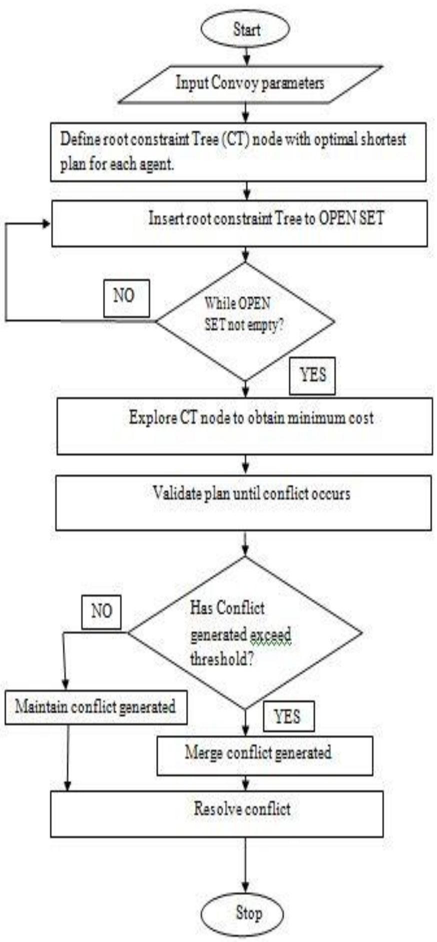

Fig. 2: Flowchart of the mXCBS Algorithm

E. Development of meta-agent technique using the look-up table approach

In this work, the mathematical model of the meta-agent technique applied is as follows:

Let:

n = number of conflict generated.

β = assigned threshold.

C= minimized conflicts.

d = difference between n and β .

l = limiting parameter.

Thus,

$$d = (n/2- \beta) \text{ and } l = (n/2-1) + d \tag{3.3}$$

Such that:

$$c = \begin{cases} n \text{ if } n \le \beta \\ l \text{ if } n > \beta \\ 0 \text{ if otherwise} \end{cases} \tag{3.4}$$

The threshold range used for this work was adopted from the work of [16] as shown in Table IV and the range of conflicts was obtained from the initial conflicts generated from XCBS algorithm.

TABLE IV
THE META-AGENT TECHNIQUE LOOK-UP TABLE [16]

Range of conflict	**Threshold**
1-10	1
11-50	4
51-100	19
101-300	63
301-500	94
501-800	211
801-1500	317

F. Development of a graphical user interface

In order to ease the development of the proposed mXCBS based search algorithm, a Visual Studio C# based graphical user interface (GUI) fitted with several buttons was developed. The screenshot of the developed GUI is shown in Fig. 3

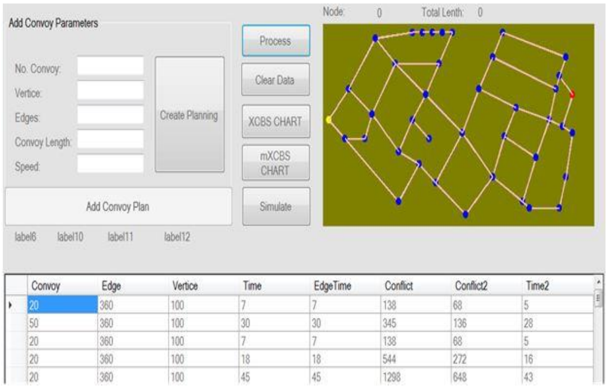

Fig. 3: Graphical User Interface

IV. RESULT AND DISCUSSION

Simulations were carried out on Virtual Studio 2015 and the results are presented based on the performance of the model. Eight samples of different network sizes were used to evaluate the performance of the proposed approach using sensitivity analysis as performance metric. Results showed higher sensitivity analysis values for the small network sizes and lower sensitivity analysis values for large network sizes. The mXCBS algorithm produced a sensitivity improvement of 42.85% over XCBS for small network sizes and 35.14% improvement for large network sizes. The results of this work showed that the output accuracy of mXCBS is robust to both small and large network sizes irrespective of number of convoys and constraints involved compared to the XCBS. The performance evaluations carried out were to check the relationship between the mXCBS and XCBS as to know the extent to which conflicts generated was been minimized. The best of every twenty (10) run of the model were presented. The Fig. 4-7 shows the comparison result obtained for the number of minimized conflicts generated for both the small and large network size using mXCBS and the standard XCBS.

A. Number of Conflicts Generated versus Speed of Convoy

For small network sizes, 100 vertices and 360 edges are used for this research work. The bar chart showing the number of conflicts generated by the XCBS and the mXCBS for the CMP using four different speeds of 20, 30, 40 and 50km/hr (for 20, 50, 70 and 100 convoys respectively) is as shown in Figure 4.1. It shows a minimization in the number of conflicts generated using the mXCBS algorithm when compared with the XCBS algorithm.

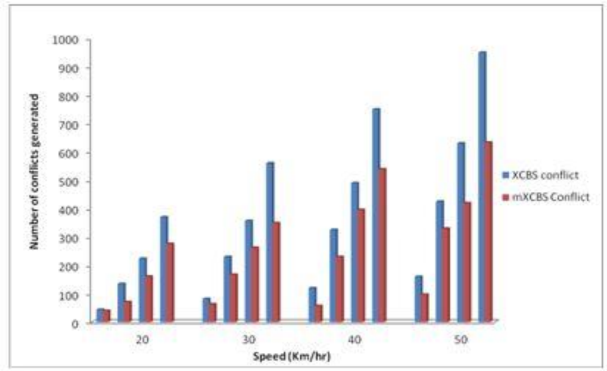

Fig. 4: Comparison of Number of Conflicts Generated versus Convoy Speed for Small Network Sizes Between mXCBS and XCBS

B. Number of Conflicts Generated versus Number of Convoys

The bar chart showing the number of conflicts generated by the XCBS and the mXCBS for the CMP using four different number of convoys (20, 50, 70 and 100) for speeds of 20, 30, 40 and 50km/hr respectively) is as shown in Figure 4.2. It shows a minimization in the number of conflicts generated using the mXCBS algorithm when compared with the XCBS algorithm

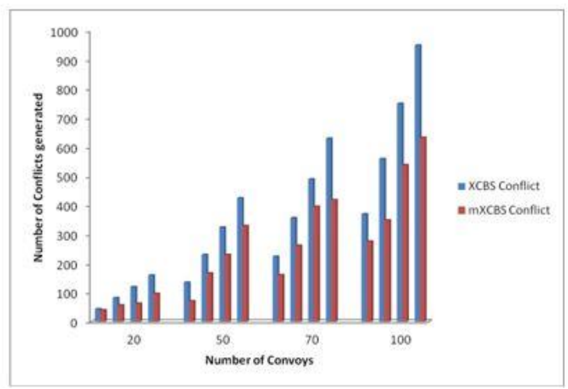

Fig. 5: Comparison of Number of Conflicts Generated versus Number of Convoys for Small Network Sizes Between mXCBS and XCBS.

C. Number of Conflicts Generated versus Speed of Convoy

The bar chart showing the number of conflicts generated by the XCBS and the mXCBS for the CMP using four different speeds of 20, 30, 40 and 50km/hr (for 100, 200, 400 and 800 convoys respectively) is as shown in Figure 4.3. It shows a minimization in the number of conflicts generated using the mXCBS algorithm when compared with the XCBS algorithm.

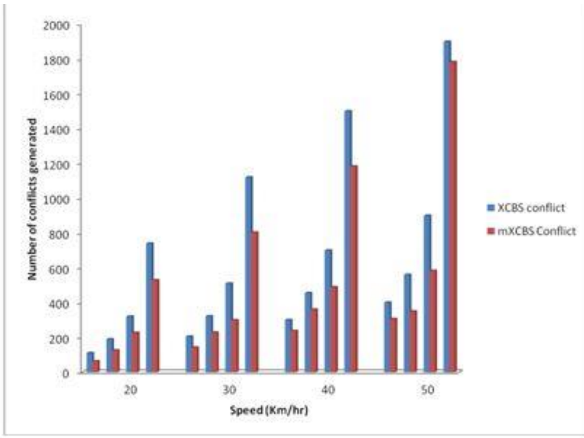

Fig. 6: Comparison of Number of Conflicts Generated versus Numbers of Convoy for Large Network Sizes Between mXCBS and XCBS

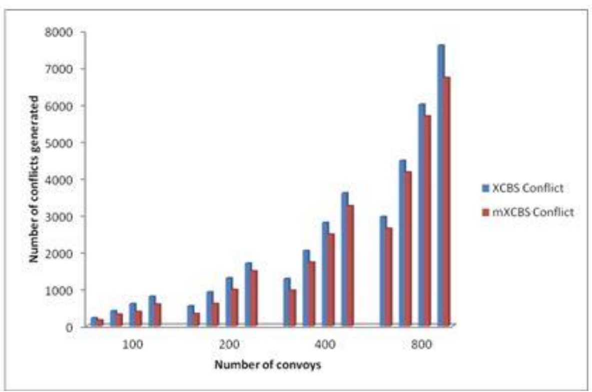

Fig.7: Comparison of Number of Conflicts Generated versus Convoy Speed for Large Network Sizes Between mXCBS and XCBS

D. Number of Conflicts Generated versus Number of Convoys

The bar chart showing the number of conflicts generated by the XCBS and the mXCBS for the CMP using four different number of convoys (100, 200, 400 and 800) for speeds of 20, 30, 40 and 50km/hr respectively) is as shown in Figure 4.10. It shows a minimization in the number of conflicts generated using the mXCBS algorithm when compared with the XCBS algorithm.

V. Conclusion and Future Work

This paper presents the development of a modified extended conflict based search (mXCBS) algorithm for addressing the convoy movement problem (CMP) of dealing with large test cases and all the constraints involved while minimizing the number of conflicts. An optimized technique for CMP using a modified extended conflict based search algorithm (mXCBS). The model was simulated in Virtual Studio 2015 simulation environment and results show the superiority of the modified algorithm over the standard XCBS. The superiority of the modified algorithm is attributed to the meta-agent technique of the modified algorithm in comparison with the original XCBS. In our next research work the performance of the mXCBS will be evaluated considering road topology and environmental condition.

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