

**Task Allocation and Motion  
Coordination of  
Multiple Autonomous Vehicles**

**- With application in automated container terminals**

by

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**A thesis submitted in fulfilment  
of the requirements for the degree of  
Doctor of Philosophy**

University of Technology, Sydney  
Faculty of Engineering  
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# ABSTRACT

This thesis focuses on developing an approach to solve the complex problem of task allocation and motion coordination simultaneously for a large fleet of autonomous vehicles in highly constrained operational environments. The multi-vehicle task allocation and motion coordination problem consists of allocating different tasks to different autonomous vehicles and intelligently coordinating motions of the vehicles without human interaction. The motion coordination itself comprises two sub-problems: path planning and collision / deadlock avoidance. Although a number of research studies have attempted to solve one or two aspects of this problem, it is rare to note that many have attempted to solve the task allocation, path planning and collision avoidance simultaneously. Therefore, it cannot be conclusively said that, optimal or near-optimal solutions generated based on one aspect of the problem will be optimal or near optimal results for the whole problem. It is advisable to solve the problem as one complete problem rather than decomposing it. This thesis intends to solve the complex task allocation, path planning and collision avoidance problem simultaneously.

A Simultaneous Task Allocation and Motion Coordination (STAMC) approach is developed to solve the multi-vehicle task allocation and motion coordination problem in a concurrent manner. Further, a novel algorithm called Simultaneous Path and Motion Planning (SiPaMoP) is proposed for collision free motion coordination. The main objective of this algorithm is to generate collision free paths for autonomous vehicles, once they are assigned with tasks in a conventional path topology of a material handling environment. The Dijkstra and A \* shortest path search algorithms are utilised in the proposed Simultaneous Path and Motion Planning algorithm.

The multi-vehicle task allocation and motion coordination problem is first studied in a static environment where all the tasks, vehicles and operating environment information are assumed to be known. The multi-vehicle task allocation and motion coordination problem in a dynamic environment, where tasks, vehicles and operating environment change with time is then investigated. Furthermore, issues like vehicle breakdowns, which are common in real world situations, are considered. The computational cost of solving the multi-vehicle STAMC problem is also

addressed by proposing a distributed computational architecture and implementing that architecture in a cluster computing system. Finally, the proposed algorithms are tested in a case study in an automated container terminal environment with a large fleet of autonomous straddle carriers.

Since the multi-vehicle task allocation and motion coordination is an NP-hard problem, it is almost impossible to find out the optimal solutions within a reasonable time frame. Therefore, this research focuses on investigating the appropriateness of heuristic and evolutionary algorithms for solving the STAMC problem. The Simulated Annealing algorithm, Ant Colony and Auction algorithms have been investigated. Commonly used dispatching rules such as first come first served, and closest task first have also been applied for comparison. Simulation tests of the proposed approach is conducted based on information from the Fishermen Island's container terminal of Patrick Corporation (Pty.) Ltd in Queensland, Australia where a large fleet of autonomous straddle carriers operate. The results shows that the proposed meta-heuristic techniques based simultaneous task allocation and motion coordination approach can effectively solve the complex multi-vehicle task allocation and motion coordination problem and it is capable of generating near optimal results within an acceptable time frame.

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**With Metha !**

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# LIST OF PUBLICATIONS

## Book chapters

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## Refereed Conference papers

3. **A. K. Kulatunga**, D. K. Liu & G. Dissanayake (2004) ‘Simulated annealing algorithm based multi-robot coordination’. *Proceedings of the 3rd IFAC Symposium on Mechatronic Systems*, September 2004, Sydney, Australia, (Paper No. 74), 411-416
4. **A.K. Kulatunga**, D. K. Liu & S. B. Siyambalapitiya (2006) ‘Ant colony optimization technique for simultaneous task allocation and path planning of autonomous vehicles.’ *Proceedings of the IEEE International Conference on Cybernetics and Intelligent Systems (CIS)*, 7-9 June, 2006, Bangkok, Thailand, 823-828
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# CONTENTS

<b>ABSTRACT .....</b>	<b>III</b>
<b>ACKNOWLEDGEMENT .....</b>	<b>V</b>
<b>LIST OF PUBLICATIONS .....</b>	<b>VII</b>
<b>CONTENTS .....</b>	<b>VIII</b>
<b>LIST OF FIGURES.....</b>	<b>X</b>
<b>LIST OF TABLES.....</b>	<b>XIII</b>
<b>ABBREVIATIONS.....</b>	<b>XIV</b>
<b>CHAPTER 1 .....</b>	<b>1</b>
<b>INTRODUCTION .....</b>	<b>1</b>
1.1.    BACKGROUND OF AUTONOMOUS VEHICLE OPERATIONS.....	1
1.2.    PLANNING AND COORDINATION .....	3
1.3.    SCOPE OF THE RESEARCH AND CONTRIBUTIONS .....	6
1.4.    ORGANISATION OF THE THESIS .....	9
<b>CHAPTER 2 .....</b>	<b>12</b>
<b>LITERATURE SURVEY .....</b>	<b>12</b>
2.1.    INTRODUCTION .....	12
2.2.    INTEGRATED APPROACHES FOR MULTI-VEHICLE TASK ALLOCATION AND MOTION COORDINATION PROBLEM.....	13
2.2.1.    EXACT APPROACHES.....	13
2.2.2.    HEURISTIC / APPROXIMATION METHODS .....	14
2.3.    TASK ALLOCATION FOR MULTIPLE AUTONOMOUS VEHICLES .....	17
2.4.    VEHICLE ROUTING AND PATH / MOTION PLANNING.....	20
2.5.    COLLISION AND DEADLOCK AVOIDANCE.....	23
2.6.    RESEARCH AND DEVELOPMENT CHALLENGES .....	25
2.6.1.    OVERALL EFFICIENCY AND SOLUTION QUALITY.....	25
2.6.2.    OPTIMISATION METHODOLOGIES.....	26
2.6.3.    PATH AND MOTION PLANNING ISSUES.....	27
2.7.    SUMMARY.....	28
<b>CHAPTER 3 .....</b>	<b>31</b>
<b>PROBLEM FORMULATION AND SIMULTANEOUS PATH AND MOTION PLANNING ALGORITHM .....</b>	<b>31</b>
3.1.    INTRODUCTION .....	31
3.2.    TASK ALLOCATION AND MOTION COORDINATION PROBLEM .....	32
3.3.    MOTION COORDINATION AND SIPAMOP ALGORITHM.....	34
3.4.    SIMULATION ENVIRONMENT.....	41
3.5.    SIMULATION STUDIES .....	43
3.5.1.    COLLISION AVOIDANCE CAPABILITY.....	43
3.5.2.    EFFICIENT MOTION COORDINATION CAPABILITY .....	50
3.6.    CONCLUSION AND REMARKS .....	58
<b>CHAPTER 4 .....</b>	<b>60</b>
<b>SIMULTANEOUS TASK ALLOCATION AND MOTION COORDINATION - STATIC ENVIRONMENT .....</b>	<b>60</b>
4.1.    INTRODUCTION .....	60
4.2.    SIMULTANEOUS TASK ALLOCATION AND MOTION COORDINATION .....	62
4.3.    MATHEMATICAL MODELLING.....	64
4.3.1.    MATHEMATICAL MODEL .....	67
4.3.2.    OPTIMISATION CRITERION .....	71



4.4.	META-HEURISTIC ALGORITHMS FOR SIMULTANEOUS TASK ALLOCATION AND MOTION COORDINATION.....	74
4.4.1.	SIMULATED ANNEALING ALGORITHM.....	74
4.4.2.	ANT COLONY OPTIMISATION.....	77
4.4.3.	AUCTION ALGORITHM.....	82
4.5.	SIMULATION STUDIES.....	84
4.5.1.	SIMULTANEOUS APPROACH VERSUS SEQUENTIAL APPROACH.....	85
4.5.2.	COMPARISON OF THE SA, ACO AND AUCTION ALGORITHMS.....	92
4.6.	DISCUSSION AND CONCLUSIONS.....	102
<b>CHAPTER 5 .....</b>		<b>105</b>
<b>STAMC APPROACH FOR A DYNAMIC ENVIRONMENT.....</b>		<b>105</b>
5.1.	INTRODUCTION.....	105
5.2.	FORMULATION OF DYNAMIC MULTI-VEHICLE TASK ALLOCATION AND MOTION COORDINATION PROBLEM.....	109
5.2.1.	MATHEMATICAL MODEL.....	109
5.3.	THE DYNAMIC STAMC APPROACH.....	112
5.4.	SIMULATION STUDIES AND RESULTS.....	114
5.4.1.	SIMULATION STUDY 1.....	114
5.4.2.	SIMULATION STUDY 2.....	117
5.4.3.	RE-PLANNING DUE TO UNEXPECTED EVENTS (SIMULATION STUDY 3).....	126
5.5.	CONCLUSIONS AND DISCUSSION.....	131
<b>CHAPTER 6 .....</b>		<b>133</b>
<b>DISTRIBUTED IMPLEMENTATION OF THE STAMC APPROACH.....</b>		<b>133</b>
6.1.	INTRODUCTION.....	133
6.2.	STAMC APPROACH IN DISTRIBUTED ENVIRONMENT.....	133
6.3.	INTEGRATION OF MPITB IN THE MATLAB ENVIRONMENT.....	138
6.4.	EXPERIMENT DESCRIPTION.....	142
6.4.1.	SIMULATION PARAMETERS.....	142
6.4.2.	CLUSTER COMPUTING ENVIRONMENT.....	143
6.5.	RESULTS AND DISCUSSION.....	143
6.6.	CONCLUSION AND FURTHER INVESTIGATIONS.....	146
<b>CHAPTER 7 .....</b>		<b>148</b>
<b>A CASE STUDY -APPLICATION OF THE STAMC APPROACH IN AN AUTOMATED CONTAINER TERMINAL.....</b>		<b>148</b>
7.1.	INTRODUCTION.....	148
7.2.	REPRESENTATION OF THE AUTOMATED CONTAINER TERMINAL.....	149
7.3.	CURRENT TASK ALLOCATION AND MOTION COORDINATION PROCESS.....	151
7.4.	EXPERIMENTS WITH THE PROPOSED STAMC APPROACH.....	152
7.4.1.	THE FIRST SIMULATION STUDY.....	153
7.4.2.	SECOND SIMULATION STUDY.....	162
7.5.	DISCUSSION.....	164
<b>CHAPTER 8 .....</b>		<b>166</b>
<b>CONCLUSION.....</b>		<b>166</b>
8.1.	INTRODUCTION.....	166
8.2.	RESEARCH OUTCOMES.....	167
8.3.	LIMITATIONS AND FUTURE OPPORTUNITIES FOR RESEARCH.....	168
<b>REFERENCES.....</b>		<b>170</b>
<b>APPENDICES.....</b>		<b>181</b>

# List of Figures

Figure 1-1: Two possible approaches to solve the multiple-vehicle task allocation and motion coordination problem.....	5
Figure 1-2: Outline of the thesis .....	11
Figure 2-1: Organisation of literature survey.....	13
Figure 3-1: Schematic representation of the multi-vehicle task allocation and motion coordination problem with three key sub-problems .....	33
Figure 3-2: Schematic representation of simultaneous path and motion planning approach.....	36
Figure 3-3: The connections of nodes for the given example.....	39
Figure 3-4: The flowchart of the SiPaMoP algorithm .....	41
Figure 3-5: The plan view of the simulation environment .....	42
Figure 3-6: The network map of the environment shown in Figure 3-5.....	42
Figure 3-7: V1's and V2's Paths obtained without considering collisions by Dijkstra algorithm (Example 1) .....	44
Figure 3-8: V1's and V2's Paths obtained by the SiPaMoP algorithm: V2 wait till V1 passes node 34 to avoid collisions (Example 1) .....	45
Figure 3-9: V1's and V2's Paths obtained without considering collisions by Dijkstra algorithm (Example 2) .....	46
Figure 3-10: V1's and V2's Paths obtained by the SiPaMoP algorithm: By changing V2's path to avoid collisions between nodes 37 and 57 (Example 2) .....	47
Figure 3-11: Paths of all vehicles obtained by Dijkstra algorithm without considering collisions (Example 3) .....	49
Figure 3-12: Paths of all vehicles obtained by SiPaMoP algorithm by considering collisions (Example 3) .....	49
Figure 3-13: Vehicles V1 and V2 performing their first tasks (Path segments between node 110 -117 of V1 and from nodes 130 –137 of V2 are shown here).....	51
Figure 3-14: Vehicles V1 and V2 towards the completion of their task 1 (both use the same path segments from nodes 116 to node 95 and vehicle 2 travels behind the vehicle 1).....	51
Figure 3-15: Vehicles V1 and V2 travelling to pick-up their 2nd tasks (at node 111 and 130 respectively) in a loop path topology .....	52
Figure 3-16: Vehicles V1 and V2 travelling to pick-up their 2 <sup>nd</sup> tasks (Between loop segment 71 - 111 and 89 -131 respectively) .....	53
Figure 3-17: Vehicle 1 (from node 110 to 117) and Vehicle 2 (from node 130 to 60) perform their first tasks by following the paths planned by the SiPaMoP algorithm..	54
Figure 3-18: Vehicle 1 (from node 115 to node 96) and vehicle 2 (from node 135 to node 60) perform their initial tasks planned by the SiPaMoP algorithm.....	55
Figure 3-19: Vehicle 1 returns to its 2nd task's origin while vehicle 2 is reaching its initial task's drop-off node (from the SiPaMoP algorithm).....	55
Figure 3-20: Vehicle 1 travels towards its 2nd task's pick-up node of 111 while vehicle 2 travels towards its 2nd task's pick-up node of 131 .....	56

Figure 3-21: Vehicles 1 and 2 performs their 2nd tasks by following the paths from the SiPaMoP algorithm .....	57
Figure 4-1: Schematic representation of the simultaneous approach .....	63
Figure 4-2: The simultaneous approach and the sequential approach .....	64
Figure 4-3: An example of tasks, vehicles' start and drop-off nodes .....	66
Figure 4-4: Task allocation process: selecting appropriate task-vehicle pairs .....	69
Figure 4-5: Vehicle-task pair's cost matrix .....	70
Figure 4-6: Flow chart of the Simulated Annealing Algorithm.....	77
Figure 4-7: Flow chart of the ACO algorithm .....	81
Figure 4-8: Simple Auction Process .....	83
Figure 4-9: Flow chart of Auction Algorithm.....	84
Figure 4-10: Flow chart of the simultaneous approach with the SA algorithm.....	88
Figure 4-11: Flow chart of the sequential approach with the SA algorithm.....	89
Figure 4-12: Variation of makespans obtained by simultaneous, sequential and SPS (without collision avoidance) respectively .....	91
Figure 4-13: Tasks allocation among vehicles, order of implementation and completion time obtained by the simultaneous approach for 8n-4m-case 2: makespan is 64.78 (stu).....	92
Figure 4-14: Task allocation among vehicles, order of implementation and completion time obtained by the sequential approach for 8n-4-case 2: makespan is 72.29 (stu)...	92
Figure 4-15: Gantt chart of the ES based the task allocation.....	95
Figure 4-16: Gantt chart of the ACO algorithm based task allocation .....	95
Figure 4-17: Task allocation results obtained from the SA algorithm.....	98
Figure 4-18: Task allocation results obtained from the ACO.....	99
Figure 4-19: Task allocation results obtained from AA .....	100
Figure 4-20: Summary of the simulation studies.....	103
Figure 5-1: Typical rescheduling methods .....	107
Figure 5-2: Flow chart of the priority based dynamic STAMC approach .....	113
Figure 5-3: Variation of makespan, tardiness and late tasks in simulation 1 .....	115
Figure 5-4: Variation of makespan with re-scheduling intervals for different batch sizes.....	116
Figure 5-5: Variation of Tardiness with re-scheduling intervals for different batch sizes.....	116
Figure 5-6: Variation of number of late tasks with rescheduling intervals for different batch sizes .....	117
Figure 5-7: The completion time and tardiness of newly arrived tasks .....	119
Figure 5-8: Gantt chart of the initial schedule at Time =0 (stu) based on the DR.....	120
Figure 5-9: Gantt chart of initial schedule at Time = 0 (stu) based on AA .....	121
Figure 5-10: Gantt chart of initial schedule at Time = 0 (stu) based on SA algorithm .....	121
Figure 5-11: Gantt chart of 1st reschedule at Time =20 (stu) based on DR .....	122
Figure 5-12: Gantt chart of 1st reschedule at Time = 20 (stu) based on AA.....	123
Figure 5-13: Gantt chart of 1st reschedule at Time = 20 (stu) based on SA algorithm .....	123
Figure 5-14: Gantt chart of 2nd reschedule at Time = 40 (stu) based on DR.....	124
Figure 5-15: Gantt chart of 2nd reschedule at Time = 40 (stu) based on AA.....	125
Figure 5-16: Gantt chart of 2nd reschedule at Time = 40 (stu) based on SA algorithm .....	125

Figure 5-17: Schematic representation of the re-planning Strategy of the STAMC approach.....	127
Figure 5-18: Gantt chart of the schedule before the vehicle breakdown .....	128
Figure 5-19: Gantt chart after re-planning of the same example .....	129
Figure 5-20: Path representations before and after the breakdown .....	130
Figure 6-1: Flow diagram describing the simultaneous task allocation and motion coordination (STAMC) approach in parallel mode .....	135
Figure 6-2 : The data path of serial computation for the task allocation and motion coordination algorithm for autonomous vehicles .....	136
Figure 6-3 : The data path of parallel computation for the task allocation and motion coordination algorithm for autonomous vehicles. ....	137
Figure 6-4 : Software architecture showing the role of MPITB and other software components. ....	139
Figure 6-5 : Computation time (seconds) for the parallel/distributed and serial/centralised STAMC approach using 4 vehicles .....	144
Figure 6-6 : Computation time (seconds) for the parallel/distributed and serial/centralised STAMC approach using 6 vehicles .....	144
Figure 6-7 : Computation time (seconds) for the parallel/distributed and serial/centralised STAMC approach using 8 vehicles .....	145
Figure 6-8 : Computation time (seconds) for the parallel/distributed STAMC approach using 4/6/8 vehicles.....	146
Figure 7-1: Container terminal at Fisherman Island ( <a href="http://www.patrick.com.au">http://www.patrick.com.au</a> ) ...	149
Figure 7-2: Arial view of the Fisherman Island Container terminal ( <a href="http://www.googlemaps.com">www.googlemaps.com</a> ) .....	149
Figure 7-3: Different regions of the container yard at Fisherman's Island .....	150
Figure 7-4: Vehicle movements screen short of the MATLAB simulation platform	151
Figure 7-5: Results of the 1st simulation .....	154
Figure 7-6: Gantt chart of the 2 <sup>nd</sup> hour schedule based on the AA .....	155
Figure 7-7: Gantt chart of the 2 <sup>nd</sup> hour schedule based on the SA algorithm .....	155
Figure 7-8: Gantt chart of the 2 <sup>nd</sup> hour schedule based on the ACO algorithm.....	156
Figure 7-9: Gantt chart of the 2 <sup>nd</sup> hour schedule based on FCFS rule .....	156
Figure 7-10: Gantt chart of the 2 <sup>nd</sup> hour schedule based on COF rule .....	157
Figure 7-11: Gantt chart of the 4th hour schedule based on the AA .....	157
Figure 7-12: Gantt chart of the 4th hour schedule based on the SA algorithm .....	158
Figure 7-13: Gantt chart of the 4th hour schedule based on the ACO algorithm .....	158
Figure 7-14: Gantt chart of the 4th hour schedule based on COF rule .....	159
Figure 7-15: Gantt chart of the 4th hour schedule based on FCFS rule .....	159
Figure 7-16: Gantt chart of the 6th hour schedule based on the AA .....	160
Figure 7-17: Gantt chart of the 6th hour schedule based on the SA algorithm .....	160
Figure 7-18: Gantt chart of the 6th hour schedule based on the ACO algorithm .....	161
Figure 7-19: Gantt chart of the 6th hour schedule based on COF rule .....	161
Figure 7-20: Gantt chart of the 6th hour schedule based on FCFS rule .....	162
Figure 7-21: Gantt chart of overall schedule for 8 hours based on FCFS rule .....	163
Figure 7-22: Gantt chart of overall schedule for 8 hours based on COF rule.....	164

# List of Tables

Table 3-1: Path selection of example 1(One vehicle waits till the other one passes away the connection) .....	44
Table 3-2: Path selection of the vehicles in example 2 (V2 changes its path to avoid collision) .....	47
Table 3-3: Task allocation information to four vehicles of example 3 .....	48
Table 3-4: Task allocation information and path details in loop based path topology	50
Table 3-5: Vehicles task allocation information and path details in conventional path topology .....	53
Table 3-6: Completion and empty travel times obtained from the two approaches ....	57
Table 4-1: Different simulation problem sizes and makespan values .....	91
Table 4-2: Makespan comparison of ACO algorithm with optimal Value.....	93
Table 4-3: Empty travel times (stu) of 8T-4m-case 1 .....	94
Table 4-4: Comparison of makespan, CPU time and empty travel times of ACO and SA algorithms .....	96
Table 4-5: Eight tasks' pick-up and drop-off nodes .....	97
Table 4-6: Four vehicles' initial positions .....	97
Table 4-7: Simulation results obtained by SA algorithm based STAMC approach ....	97
Table 4-8: Simulation results obtained by ACO based STAMC approach .....	98
Table 4-9: Simulation results obtained by AA based STAMC approach .....	99
Table 4-10: Comparison of Makespan and vehicle utilisation of three methods .....	100
Table 4-11: Makespan comparisons of ACO, SA and Auction algorithms.....	101
Table 4-12: Hardware and Software Specification of Simulation Studies .....	102
Table 4-13: Algorithms and parameter values.....	102
Table 5-1: Variation of rescheduling intervals with tardiness, late tasks and tasks scheduled.....	115
Table 5-2: Task allocation among the four vehicles before and after vehicle 4 breaks down.....	129
Table 6-1 : Algorithm and simulation parameters .....	142
Table 6-2 : Cluster computing hardware and software environment.....	143
Table 7-1: Task allocation information of the existing method of one hour duration .....	152
Table 7-2: The makespan and computational cost of the first scenario.....	154

# Abbreviations

ACO	Ant colony optimization
AGV	Automated guided vehicle
AV	Autonomous vehicle
BD	Breakdown
BS	Batch size
BSA	Beam Search Algorithm
CIM	Computer Integrated Manufacturing
COF	Close proximity task first
CR	Cooling rate
CT	Container Terminals
DR	Dispatching Rules
FCFS	First-Come-First-Served
FMS	Flexible Manufacturing Systems
GA	Genetic algorithm
LAN	Local area network
MC	Motion Coordination
MPI	Message-Passing Interface
MS	Makespan
PP	Path Planning
RSI	Rescheduling interval
SA	Simulated Annealing
SCs	straddle carriers
SiPaMoP	Simultaneous Path and Motion Planning
SPS	Shortest Path Search
STAMC	Simultaneous Task Allocation and Motion Coordination
stu	simulation time units
TA	Task Allocation
TEU	Twenty feet Equivalent Units
TS	Tabu Search