Dynamic Resource Allocation with Maritime Application (DRAMA)

Final Report

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13th March 2015

Abstract

An important challenge within the offshore industry and sea traffic preparedness is how to plan and optimise the positioning of a fleet of vessels in a dynamic, everchanging environment such that operating costs and risks related to health, the environment, and safety are reduced, whilst services and profit are improved. In Norway, the Norwegian Coastal Adminstration runs a vessel traffic service centre in the town of Vardø that is responsible for a fleet of tugs patrolling the northern coastline of Norway. Tug fleet optimisation algorithms can be designed to solve the problem of dynamically positioning such a fleet of tugs in order to mitigate the risk of oil tanker drifting accidents. In this project, we modelled the tug fleet optimisation problem in both 1D and 2D and developed new methods for solving it, including 14 different variants of a receding horizon genetic algorithm as well as several variants of a receding horizon mixed integer programming algorithm. We also developed two evaluation heuristics for measuring the performance, or merit, of such algorithms. The algorithms were tested for a large number of simulation scenarios. Extending the original project description, we also re-implemented the receding horizon genetic algorithm in a more suitable programming language and studied parallelisation of genetic algorithms and pseudo-random number generators. The work resulted in several conference presentations and seven publications, far exceeding the target of two publications. Research on fleet optimisation has continued after the project ended through the work of a PhD candidate expected to complete his work late 2016. In addition, the knowledge, skills, and methods gained and developed during the project have led to further research funding in other research areas as well as integration in research-based education both at the bachelor and master level at Aalesund University College.

1 Introduction

This report describes a research project funded by Regionalt Forskningsfond Midt-Norge and the Research Council of Norway entitled *Dynamic Resource Allocation with Maritime Application* (DRAMA), with grant no. ES504913. The following sections present the original project description (background and motivation; details about the project group members; budget, financing, and timeframe; main goal and subgoals; research problems; and project partners), the results, and conclusions.

2 Project Description

The following is an English translation of the project description, which was revised during spring 2013 after notice from the Research Council of Norway that funding had been granted[1].

2.1 Background and Motivation

An important challenge within the offshore industry and sea traffic preparedness is how to plan and optimise the positioning of a fleet of vessels in a dynamic, everchanging environment such that operating costs and risks related to health, the environment, and safety are reduced, whilst services and profit are improved. In Norway, the Norwegian Coastal Administration (NCA) is responsible for the tug vessel preparedness along the coast of Norway. By monitoring and assessing the current and future (predicted) state of factors such as the traffic situation, ocean currents, wave heights, and weather conditions, the NCA attempts to plan for and position their fleet of tugs in a best possible manner. Currently there exists no method, algorithm, or computer programme that can do this objectively and fact-based. Instead, the decision-making and positioning of the tug fleet is done ad hoc on a subjective basis by human operators at a vessel traffic service (VTS) centre in the town of Vardø.

Basing such important decisions solely on human knowledge and experience is prone to error, especially with the projected increase in ship traffic and the complex situations that may arise and that can sometimes be difficult to read

[1]The Norwegian version can be found at the project website at http://blog.hials.no/drama

and fully understand. Thus objective and calculating methods implemented in a computer programme can be a useful decision-support tool for the VTS operators. Moreover, such methods may also be transferrable to, and be of aid for, fleet optimisation in the offshore industry. With the planned growth and expansion of oil and gas fields in the High North, the ship traffic will see a huge increase during the coming years, for example with an increasing number of platform supply vessels (PSVs).

The development of novel methods for tug fleet optimisation (TFO) in the DRAMA project has the potential of leading to the development of software prototypes and implementation of actual decision-support tools with real-world application. The socioeconomic benefits are potentially great in terms of a reduced number of accidents that can lead to loss of human lives and environmental damage. In addition, there are benefits in terms of faster and safer marine operations and less transportation expenses.

2.2 Project Group Members

The project group consists of the following core people employed at the Aalesund University College[2] (AAUC):

1. Associate Professor Robin T. Bye (project manager), AIR-ICT
2. Professor Hans Georg Schaathun, AIR-ICT
3. Associate Professor Siebe van Albada, AIR-Natural Sciences
4. Senior engineer Mikael Tollefsen, AIR-ICT
5. PhD Candidate Brice Assimizele, AMO-Maritime Technology

In addition, several people will contribute towards the project, most importantly Associate Professor Johan Oppen at Molde University College, who is supervising the PhD candidate; Senior Advisor of Maritime Safety at the NCA, Trond Ski; and Associate Professor Johannes Royset at the Naval Postgraduate School, Monterey, California, USA.[3]

[2] AIR: Faculty of Engineering and Natural Sciences; AMO: Faculty of Technology and Maritime Technology

[3] Note that this is the original project description found in the research application and Royset would later become co-supervisor for Assimizele.

2.3 Budget, Financing, and Timeframe

The project budget is 1 MNOK and is partially funded by AAUC (500,000 NOK) and Regionalt forskningsfond (RFF) Midt-Norge (500,000 NOK).

The project intended startup date is 1 September 2013 and intended finish date is 30 June 2014. The project will, however, continue after this date funded by the professorship scholarship of the project manager (runs until August 2015) and the PhD scholarship (runs until October 2016).

2.4 Main Goal

The main goal of the project is to develop new and stringent methods for dynamic resource allocation with maritime application based on methods from areas such as artificial intelligence, cybernetics, stochastic optimisation, informatics, and statistical physics.

2.5 Subgoals

The project manager has already developed a dynamic optimisation algorithm called receding horizon genetic algorithm (RHGA) able to assist VTS operators with dynamically optimising the positioning of the tug fleet. This work has resulted in two publications (Bye et al., 2010; Bye, 2012). Moreover, project group member Brice Assimizele has together with his supervisors developed an exact method for dynamic tug vessel allocation (Assimizele et al., 2013). A subgoal of the project is to further develop the RHGA with respect to implementation and use of real data and to continue the good cooperation with the NCA. It is also a subgoal to develop new methods from other scientific areas, and compare the methods. The methods shall be of use not only for the tug vessel preparedness of the NCA but should also be transferrable to other domains such as fleets of PSVs or other ships in the offshore industry. In addition, we wish to continue the work on developing exact methods (benchmarks) for further assessing such methods.

The work should result in presentations at international conferences and at least two publications on level 1 or 2. In subsequent projects, the goal is to refine and implement our methods for fleet optimisation as a standard decision-support tool for the NCA and for offshore companies.

The subgoals can be summarised as follows:

M1 Further develop and improve existing RHGA algorithm for dynamic resource allocation of the NCA tugs, and explore other uses.

M2 Develop new methods based on methods from the scientific areas listed under "Main Goal" that can be used across a number of disciplines and domains, including the NCA tugs but potentially also for PSVs or other ships in the offshore industry.

M3 Develop benchmarks with exact solutions and theoretical computational speeds for quality assessment of the methods.

M4 Present the work at international conferences and disseminate the results in two publications on level 1 or 2.

2.6 Research Problems

Problems in dynamic resource allocation are often complex, nonlinear, nonconvex, stochastic, etc. In the field of operations resarch, the method of optimisation is commonly used to solve simpler problems statically, that is, by finding an optimal static solution for special cases that do not vary with time. However, the problem with this approach is the fact that the real world is inherently dynamic and changing. The weather conditions are constantly changing, as is the traffic situation, thus new situations constantly arise and new choices must be made. In this project we want to combine the best parts from areas such as computational intelligence, cybernetics, operations research, stochastic optimisation, informatics, and statistical physics. We have already achieved promising results through the work of the project manager's work on the TFO problem and respective publications, as well as the recent publication by the PhD candidate.

The main research problems that need to be solved in order to reach the subgoals M1–M4 can be summarised as follows:

P1 Review factors influencing the VTS operators' choices for positioning their fleet of tugs and implement these realistically in the RHGA algorithm. Examine the needs for optimisation of offshore vessels such as PSVs and adapt the RHGA to these needs. Perform more testing with realistic data and examine performance with respect to real-time requirements.

P2 In relation to P1, examine alternative problem formulations and solutions for control of the NCA tugs or offshore PSVs.

P3 In relation to P1 and P2, define og possibly redefine problem formulations such that exact solutions exist and can be found in reasonable time. Develop test cases for these formulations that can act as benchmarks for comparing algorithms with respect to computational speed, performance, and more.

P4 Achieve sufficiently good results with new methods such that the work is a significant contribution to world knowledge and worthy of publication. Find good conferences with respect to themes and problem description where the work can be presented and published. Develop contact networks within the offshore industry for future potential cooperation and real-world implementation of methods. Write applications for more funding.

2.7 Project Partners

The following institutions are partners in the project:

- Aalesund University College
- The Norwegian Coastal Administration
- Molde University College

3 Results

During the course of the project, the work has diverted slightly from the original plan described in Section 2 in that the work has focussed solely on the tug fleet optimisation problem and not included any research related to the offshore industry. The reason for this is that the scope of the TFO problem was larger than expected and also led to new research questions which we had not thought about initially. For this reason, the research results exceed reaching the subgoals listed in the original project description and also divert slightly. Note however, that with small modifications, the algorithms we have developed can be transferred to other domains where dynamic resource allocation is needed, e.g., for optimising a fleet of PSVs.

3.1 Goal Achievements

The main goal has been achieved by means of completing subgoals M1–M4.

M1 — further develop and improve RHGA

The original RHGA was further developed and greatly improved as documented in Bye and Schaathun (2014):

- the entire algorithm and its simulator framework was recoded into the functional programming language Haskell, which has a number of advantages, including
  - modularity and easier extensions and modifications;
  - code maintenance, readibility, conciseness, and easier debugging; and
  - suitability for parallelisation.
- more than fifty-fold increase in number of simulation scenarios, making results much more reliable.
- genetic algorithm component extended with more options and easier to adapt to new problems.
- 1D model of problem formulation more concise and mathematically stringent.

M2 — develop new methods

A total of 14 different cost functions were developed and evaluated as documented in Bye and Schaathun (2014, 2015a,b). Configuring the RHGA with each of these cost functions essentially is equivalent to using 14 different TFO algorithms. In addition, a 2D nonlinear mixed integer programming (MIP) formulation was developed, in which the problem formulation is redefined as a 2D model, and the GA component of the RHGA is replaced by MIP to form a RHMIP algorithm. This work also included two linearisation methods and employed real, historical traffic data. A manuscript detailing this work is nearly finished and will be submitted to a level 1 or 2 journal (Assimizele et al., 2015).

M3 — develop exact solutions and benchmarks

An exact optimal solution to the original cost function by means of MIP and used with the RHGA was developed in Assimizele et al. (2013). For the 2D nonlinear MIP model in Assimizele et al. (2015), two linearisation methods with proven upper and lower solution bounds were developed, hence the level of accuracy can be chosen by the user, with higher accuracy at the cost of longer computational times.

Thorough investigation of theoretical or practical algorithmic speed was not undertaken but some quantitative results regarding computational time was done by Assimizele et al. (2015).

In order to compare the merit of different TFO algorithms, two evaluation heuristic were developed and tested by means of a computational simulation study (Bye and Schaathun, 2015a,b).

M4 — conferences and publications

Please see Sections 3.3 and 3.4 below.

3.2 Other Results

GAs lend themselves naturally to parallelisation, which can greatly improve the computational speed of an algorithm. However, parallelisation of code in the functional programming language Haskell used in the DRAMA project imposes strict demands on pseudo-random number generation (PRNG), which lies at the core of many optimisation algorithms, including GAs. Hence, a decision was made to investigate these challenges further, which resulted in a conference presentation and level 1 publication (Schaathun, 2014).

Furthermore, a more in-dept study of so-called splittable PRNGs followed and the resulting level 1 journal paper is currently under review (Schaathun, 2015).

3.3 Conferences and Seminars

Research results from the project have been presented at, and published in the proceedings of, the following conferences:

- the 27th European Conference on Modelling and Simulation (ECMS'13) (Assimizele et al., 2013);
- the 28th European Conference on Modelling and Simulation (ECMS'14) (Bye and Schaathun, 2014);
- Norsk Informatikkonferanse (NIK'14) (Norwegian Conference on Informatics) (Schaathun, 2014); and
- the 4th International Conference on Operations Research and Enterprise Systems (ICORES'15) (Bye and Schaathun, 2015a).

Abstracts were also submitted and accepted for presentation at the INFORMS Annual Meeting in 2013[4] and Operation Days 2014[5]. Finally, a number of internal seminars have been held at Aalesund University College and Molde University College.

3.4 Publications

The DRAMA project was a continuation of earlier work by the project manager and colleagues and tat was published as a conference paper (Bye et al., 2010) and a publication in a book series (Bye, 2012). In the period following the grant award by the Research Council of Norway but before the official start of the project in September 2013, the DRAMA research group managed to give the project a head start by partly completing subgoal M3, and had the results published in a conference paper (Assimizele et al., 2013). After the project startup, the publications that are a direct result of the DRAMA project's research include three published conference papers (Bye and Schaathun, 2014, 2015a; Schaathun, 2014), one publication that has been accepted for publication in a book series and will appear during 2015 (Bye and Schaathun, 2015b), one journal paper (Schaathun, 2015) that has been submitted and is currently under review, and one journal paper that is under preparation (Assimizele et al., 2015).

In summary, excluding the two pre-project papers, the project has resulted in a total of seven publications that all qualify for publication points as recognised by the Norwegian Register for Scientific Journals, Series, and Publishers, with scientific levels as indicated in parentheses:

- 4 conference papers (level 1);

[4] Brice Assimizele: https://informs.emeetingsonline.com/emeetings/formbuilder/clustersessiondtl.asp?csnno=18303&mmnno=248&ppnno=70630

[5] Johan Oppen: https://symposia.cirrelt.ca/JOPT2014/fr/schedule?slot_id=863text

- 1 book series papers (level 1);
- 1 journal paper currently under review (level 1); and
- 1 journal paper currently under preparation (level 1 or 2).

Subgoal M4 of the project was to present the work at international conferences and publish two papers on level 1 or 2. With five accepted publications and two journal papers awaiting, the project has thus exceeded its publication goal by far.

Publications can be found on the project's website[6].

3.5 Networking and Future Collaboration

The project has strengthened the cooperation with the NCA, for example by means of a field trip to the Vardø VTS. This has been important to ensure that the research is relevant and realistic. Many academics and professionals at conferences have expressed great interest in the project, including a researcher at the company Liquid Robotics and an academic at Bergen University College, who both are interested in collaboration and application of the project algorithms on aquatic swarm robots. Most important has been a field trip by the PhD candidate Brice Assimizele to the USA and the strong cooperation with Johannes Royset, who is the Associate Chair of Research and Associate Professor of Operations Research at the Naval Postgraduate School in Monterey, California. This cooperation has led to Royset now actively co-supervising the PhD candidate.

3.6 New Research and Education Activities Spawned by DRAMA

After the completion of the DRAMA project, Bye and Schaathun together with colleagues have co-founded the research group Software and Intelligent Control Engineering (SoftICE) Laboratory[7] at AAUC. The SoftICE lab will continue working with some of the core components of the DRAMA project, namely functional programming, parallel computing, and genetic algorithms. Among other things, this work has led to research funding for intelligent

[6] http://blog.hials.no/drama
[7] http://blog.hials.no/softice

virtual prototyping of offshore cranes using artificial intelligence and has already resulted in a publication (Bye et al., 2015).

In addition, further delving into functional programming and GAs, the same two people have developed two new courses on artificial intelligence in AAUC's new master programme in simulation and visualisation, as well as using the TFO problem as part of the research-based teaching component of a third year bachelor elective in intelligent systems.

Research on the TFO problem is also continuing with the work of PhD candidate Brice Assimizele, who will expand on his previous work (Assimizele et al., 2013, 2015) and develop new methods, for example using superquantile risk (also known as conditional value-at-risk (CVaR)).

4 Conclusions

The DRAMA project has been a success in that the desired goals were reached, most notably by the number of publications (seven) greatly exceeding the target number of publications (two). Part of the reason for this was the unforeseen need to explore and solve challenges related to parallelisation and pseudo-random number generation. Knowledge gained and the new methods developed have been transferrable to and useful in other domains in research and education (see above). In addition, research on the particular TFO problem of the DRAMA project is being continued by a PhD candidate at AAUC who is expected to complete his work late 2016.

5 Acknowledgement

The project members are grateful for the support provided by Regionalt Forskningsfond Midt-Norge and the Research Council of Norway for this project entitled *Dynamic Resource Allocation with Maritime Application* (DRAMA), grant no. ES504913.

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