Towards ARTS: Releasing Latent Road Network Capacity through better Path Planning Management

Dr Haitam M. Laarabi
Research Fellow (iMFV member)
DELAB, University of Genoa, Italy

Dr Muna Hamdi
Leader & Founder
iMobility: FutureVision Collaboration Group (iMFV)

Abstract

Road traffic systems are complex, heterogeneous, expensive to maintain, and difficult to optimise. It raises several challenges related to congestion, environment, safety, support, information management, scheduling and large software maintenance. Incorporating autonomic principles of self-management to transport management systems will aim directly at tackling the challenges and overcoming the shortfall of conventional systems. Among the main challenges are the extensively studied path planning algorithms, used in traffic flow management, navigation and scheduling applications. In this paper, we give an overview of our current research direction aiming towards the gradual development of road traffic management systems using a set of distributed systems, endowed with self-management properties. We then investigate developing autonomic self-management properties for path planning. We propose hyper-heuristic model for the selection and construction of path planning heuristics, to be used in building autonomic properties for the future Autonomic Road Transport Support (ARTS).

Keywords: Autonomic Systems, ARTS, Path Planning, Distributed Decision Making, Hyper-heuristics, Road Traffic Management Systems, Transport.

1. INTRODUCTION

The application of the new Information and Communication Technologies (ICT) in traffic management, known as Intelligent Transport Systems (ITS), obliterated barriers and succeeded in setting records and continue to do so. However, this success gave birth to a complexity intrinsically related to ICT, which on one hand, impedes progress towards the next technological era and on the other hand, makes impossible to maintain for long-term the viability of the automation. Internet and portable devices, such route navigation devices, generate Tera bytes of data (Laarabi et al., 2014) and entangled information from individuals' daily life, which adds another layer of complexity. The objectives of ITS, which encompass all cited complexity in the form of System of Systems (SoS) (Jamshidi, 2011), seem to be unfeasible with the current rate of systems' expansion. ITS operators will not be able to grasp the systems complexity in time for efficient traffic management, thereby degrading systems' performance; risking safety and reliability. Even if there are enough highly experienced engineers to maintain and operate the system, the amount of effort and the difficulty of the tasks due to system's complexity will inevitably cause human/system's error. As a result, operating and maintaining the system will cost more than operators would afford, hence reducing system's dependability.

An ultimate solution to break through this barrier towards the next technological era, an action was started by the approved COST[1] Network on Autonomic Road Transport Support (ARTS) systems, to explore the potential of embedding autonomic properties into the design of transportation systems (McCluskey, 2011). The goal is to seek the building of complexity into the transport systems that encapsulate the intricate decision-making process under generic objectives inserted by the operators.

This work is part of an investigation addressing the steps required in order to take advantage of the existing ITS infrastructure, models and algorithms to build future ARTS. We contribute to this quest by focusing on the use of path planning in the development of self-managed properties within an ARTS. In the following sections, we propose an overview of a hierarchal system of systems approach to future traffic management systems. Where we look into developing traffic management capabilities using a set of distributed systems, endowed with self-management properties, section 2. In Section 3, we define the hyper-heuristic approach as a promising solution to augment path planning and goal optimisation processes with self-management properties. Finally, the conclusion is drawn in Section 4.

2. DISTRIBUTED ARTS FOR BETTER TRAFFIC MANAGEMENT

This section gives an overview of the steps we are currently exploring towards the design of an ARTS architecture, with emphasis on implementing distributed/multi-agent path planning algorithms to be used for multi-objective, real-time, dynamic planning and scheduling tools within transport engineering applications, to enable autonomic properties.

Our goal is to research, design and implement an architecture, which incorporates key technologies that would allow transport systems to competently implement autonomic behaviour. Our focus is on developing an ARTS that would scale to manage wider regional networks, adaptable to change in environment and traffic demands, have ability to anticipation behaviour, predict consequences, and collaborate in a distributed environment using knowledge of a mixture of "goals" and intervention capabilities (which may be conflicting) of the various stakeholders.

Traffic management systems suffer increasing complexity with finite network capacity that raises the demand for an ARTS approach that is scalable and adaptive to change, able to create its goals using its self-management properties. Figure 1, describes a regional ARTS that is dependable and adaptable to traffic change and demands using hierarchal modular approach and self-capabilities; thereby unlocking vendor's dependency without the need for costly re-programming. An autonomic system creates its goals according to its self-management properties, where the system creates a process to achieve these goals, and the system carries out the process itself. While engineers create the system and embed it with self-management properties (McCluskey, 2014, AWAN broadsheet 2014). For example, as the complexity of the system increase, an operator may suggest a policy that is conflicting; thereby transferring the problem elsewhere or creating other problems in the local or regional network. Future, systems should be able to detect such conflict and therefore has the ability to approve or disapprove a policy, amend or suggest a better policy. Taking into consideration constraints such as safety and reliability, the aim is to alleviate some of the current system's operator tasks allowing for a change of roles; where instead of controlling the system directly, the operator may defines general policies and rules that guide the self-management process.

An ARTS should be able to interpret, reason with, plan and manage the network, while adapting to new goals or policy directives communicated by the operator. The system will use a library of traffic and event models to be used in assessing the current traffic flow and aid creating current and next interval goals (Hamdi et al., 2007 & 1998). Developing techniques

[1] European Cooperation in Science and Technology

that deals efficiently with uncertainty (learning and predicting using real-time and historical heuristics) is essential to increase the level of trust in the system ability, hence increasing users' (operator or traveller) acceptability of ARTS (Hamdi, 2015).

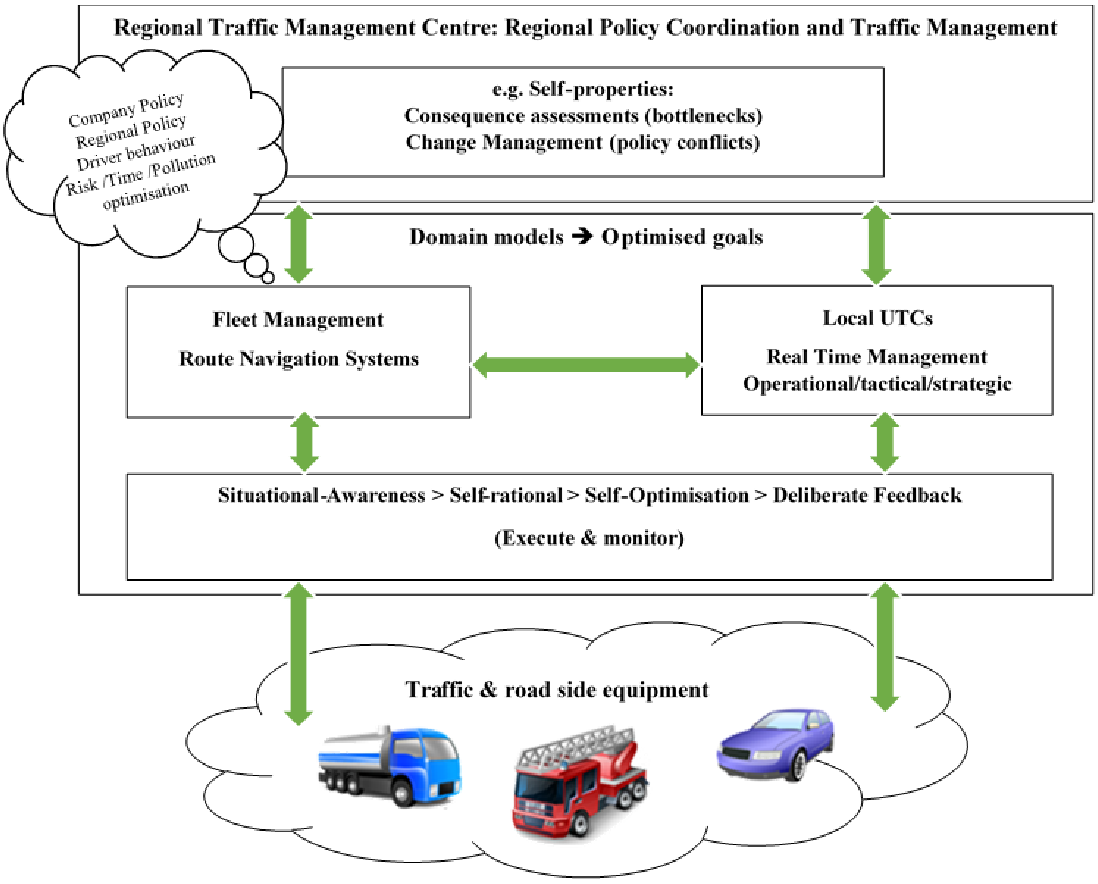

Figure 1. Better management of the transport network through incorporation of autonomic properties and distribution

Traffic models developed with time by the system (situation assessment/self-learning) allow for future situation prediction and early adaptation to traffic changes. Historical, real time and predicted information (data) can be used for predicting the next state. Self-optimisation refers to a system able to automatically optimise and adapt itself and its resources based on the current and predicted state of the environment. In the case of path planning, it would be the search for the best found solutions for the current environment status and time interval.

A self-learning system is able to automatically learn new patterns from previous situations, and generate better heuristics. For example, this would be a system capable of being aware of the change in traffic pattern with time in response to events, accidents, holidays and school departure time.

The self-configuration occurs when the autonomic system is able to automatically modify its configuration according to the change in the environment. The choice of configuration will depends on the domain model, related policies, adaptation to change and optimisation process. For example, in disaster situation the operators' priority is to get the traffic safely out of the disaster zone. Therefore, the pollution levels in other adjacent regions (where the traffic will flow to) may no longer be a priority during the disaster management period.

The performance of traffic management systems decrease when scaling up to large networks. To improve the regional management we propose a collaborative autonomic systems/agents (AS) with decentralized decision-making approach. Where, each AS has an access to partial information and need to collaborate with other AS to share information to support the process of making an efficient judgment. For example, an autonomous or pseudo-autonomous car entering a region managed by an Urban Traffic Controller, should be able to exchange information on the status of the network; such as an update of allowed road speed and new regulations related to the region. In (Kephart and Chess, 2003), an AS at the higher level, consists of a large and tangled hierarchy of self-governing systems, which are composed of a variety of interacting self-governing components that in turn, at the next level down, incorporate other sets of autonomous, self-governing and interacting components.

The application of these concepts and techniques will be directed into the design of a decentralized and self-governed planning and scheduling system. The main objective of this system is to be able to generate a plan (or route) taking into consideration the partially unknown and dynamic environment. Each components and subsystems are endowed with self-descriptive and management properties that can collaborate and communicate. Figure 2 proposes a standard communication protocol allowing ARTS and conventional ITS systems to share their ontological knowledge using self-described interface mechanism. The communication protocol should incorporate its own ontology as well as to bear the systems ontological knowledge, such with the WOL (Web Ontology Language) that is a family of knowledge representation languages (Milea et al, 2012). This will enable ARTS systems to learn new communication protocols and collaborate with new systems with different ontology.

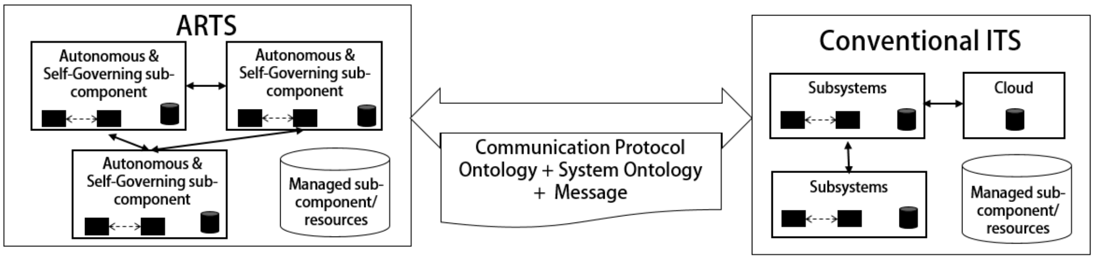

Figure 2. Allowing ARTS and conventional ITS systems to share their ontological knowledge through an appropriate standard communication protocol

In the next section, we discuss developing path planning algorithms with self-management properties while ensuring a distributive collaboration among various actors such as urban traffic controller, GPS navigators, autonomous cars and public transport network, to help at releasing latent network capacity. We propose, the concept of hyper-heuristics as promising solution to build autonomic properties for path planning while giving room to collaboration and situational awareness.

3. HYPER-HEURISTIC CONCEPT FOR BUILDING SELF-MANAGEMENT PROPERTIES FOR PATH PLANNING

The optimisation objective in dynamic environments is no longer 'to find the global optimum' but to continuously track the optimum or find a dependable solution in the presence of perturbation within the time interval given to search for a solution (Madureira et al. 2009, and Hamdi et al, 2007).

In this section we propose the use of metaheuristics approaches in path planning that form a collaborative effort to find the best solution within a specific decision-making time interval. Path planning in dynamic environment, has to deal with sudden events and changing goals set explicitly or implicitly by users or operators, and in many cases, a predefined metaheuristics cannot be efficient in every situation or context. The reason behind the variety for path planning and optimisation techniques stems from advantages and drawbacks of each one of them. Therefore, researchers are exploring hybrid approaches and new heuristic optimisation techniques such as nature inspired optimisation. For example, the use of Ant Colony, Genetic and Evolutionary algorithms or a mix of dynamic programming and heuristics search such as Tabu and A*.

An example of similar approach in (Madureira et al. 2009) which combine nature inspired optimisation techniques and autonomic multi-agent approach, for developing industrial distributed and dynamic scheduling systems. The collaborative autonomic agents (resources) process system's dynamism (new jobs arriving, cancelled jobs, changing jobs attributes, etc); to change/adapt the parameters of the basic algorithm according to the current situation; to switch from one Meta-Heuristic algorithm to another and to cooperate with other agents.

An example of a heuristic optimisation algorithm is the 'A* search and its variants', which is able to find suitable paths that map an initial state to a goal state, while heuristics can be applied to limit the extent of the search and so control its execution time. A* uses a knowledge function as well as heuristics to direct the search toward the goal. Although, in practice, significant numbers of undesirable solutions are pruned, the number of nodes in an A* search space can grow exponentially, where producing an optimum solution is likely to take longer than the time interval available. This problem increases in complexity particularly in real-time dynamic environment with multiple objectives.

(Hamdi et al, 2007) give an overview of A* variants used to achieve optimal or near-optimal solutions within the given time constraint. To guarantee deadline compliance, there is normally a trade-off between the complexity of the search that is undertaken and the quality of the resulting search. (Hamdi et al, 2007) proposes an elevator dispatching algorithm formulated as a heuristic search and is implemented using a novel extension of A* search, termed *prioritised* A* *(PA*)*, that retains the desirable admissibility and monotonicity of A*. PA* makes best use of the limited time available by ensuring the dispatcher considers the most important aspect of the problem first, namely to give each elevator (resource) its first assignment. In a manufacturing process, this is equivalent to ensuring that each machine is immediately given its first job, while the determination of the detailed order of the remaining jobs is refined later. In transport and logistics, similar approach may be applied in for example Heathrow transit pods, managing the distribution of traffic flow for example during incidents and events or when managing the number of trucks released within the day/evening from certain logistics hubs within region/regions.

A traffic management system is an example of a real-time multi-objective systems operating in a dynamic environment. Once aware of any change in traffic flow (caused for example by sudden accidents, events, short or long term changes) the system may respond by changing traffic lights, updating message signs, or transmitting new regional policies. All these actions will also affect the route planning calculations for the vehicles entering the region.

Consequently, path planning requires a more generic problem solving approach, which deals in the same time with multiple planning criteria, dynamics and uncertainty, as well as to search space and time constraints. The approach need also to sustain the distributed aspect discussed in section 2. Incorporating the autonomic aspect of self-knowledge, self-optimisation, self-configuration, self-learning and situational awareness properties in path planning will inevitably lead to better management of traffic flow and network capacity.

We suggest hyper-heuristics as a solution for developing the autonomic properties in path planning. The concept of hyper-heuristic dates back to the sixties, though the term was coined in 1997 for automated theorem proving methodologies that combine various artificial intelligence approaches (Burke et al., 2010). Since the dawn of 21st century, the term was used in the context of combinatorial optimisation to characterize a heuristic that search in the space of heuristics (Ross, 2005). While metaheuristics (or low-level heuristics) are heuristics that search a space of solutions.

Most heuristics are context dependent, hence very sensitive to change with strengths and weaknesses. Therefore, it makes sense to design automated strategies that try to optimise problem solving by either choosing the right heuristic or by combining multiple heuristics that make up for the weaknesses of each other. This step is represented by the Selection module on Figure 3. In the state of arts, one can find several hyper-heuristics approaches for different optimisation problems (Misir et al., 2010), (Ochoa et al, 2009), (Ouelhadj and Petrovic, 2008). These approaches are usually based on either incremental construction (from a blank solution) or perturbation (reconfiguration) of low-level heuristics (Özcan et al, 2010). The latter consist in finding an initial solution, randomly or through a straightforward construction, and then use swapping and shifting techniques to investigate better solutions in the neighbourhood.

In Figure 3, we propose a hyper-heuristic model with self-management autonomic properties. The S*election/Construction module* uses algorithms such Rule-based Fuzzy Inference System to construct a heuristic suitable for the problem P_0. This process is enhanced by information provided by the *Learning Base module* as a form of assessment feedback. This enhancement refers to the *self-optimising* property. *Self-learning* is undertaken during the assessment process where the Learning Base module is provided with the obtained scores. Both Network and Metaheuristics modules form a knowledge base, where the latter refers to the ontological knowledge of metaheuristics. Finally, generic objectives, policies and distributed information can be provided for the algorithm implementing the hyper-heuristic model through the Network base.

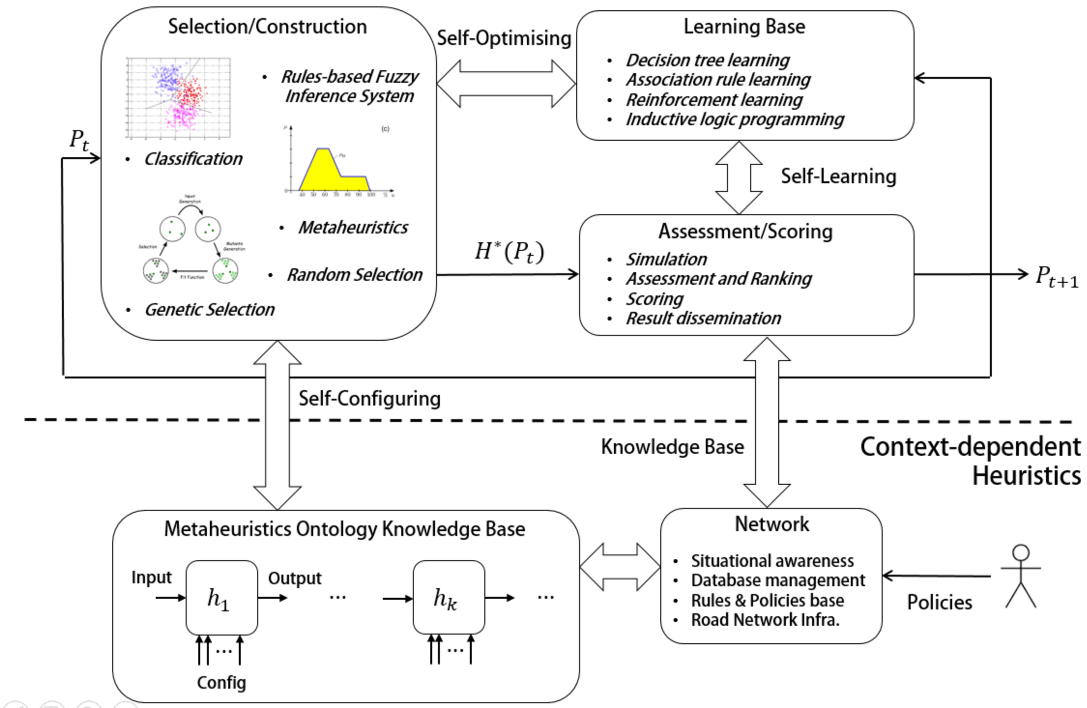

Figure 3. A hyper-heuristic model with autonomic properties, where P_t refers to the solution at iteration t, H^* denotes the selected/constructed metaheuristic, h_k is the kth metaheuristic in the knowledge base

4. CONCLUSION

This paper explored the use of hyper-heuristic concept as a mean to build self-management properties within path planning and resource management tools in traffic management systems. The application of these concepts and techniques will be part of the design of a decentralized and self-governed planning and scheduling system. The main objective of this system is to be able to generate plans (or routes), manage resources, taking into consideration the partially unknown and dynamic environment, AS and conventional ITS that exist in the neighbourhood. In summary, future ARTS would scale to manage wider regional networks, adaptable to change in environment and traffic demands, have ability to anticipation behaviour, predict consequences, and collaborate in a distributed environment using knowledge of a mixture of "goals" (which may be conflicting) and intervention capabilities of the various stakeholders.

AKNOWLEDGEMENTS

We would like express our gratitude for the support provided the iMFV Collaboration Group with special thanks for Pr. McCluskey, University of Huddersfield, and iMFV-AWAN project team. Special thanks to Pr. Roberto Sacile as the DELAB Laboratory of University of Genoa and to our industrial partner a leading Italian Petrochemical Company Eni R&M Division.

REFERENCES

AWAN broadsheet (2014), iMFV Collaboration Group, "Autonomic Wide Area Network AWAN Manager", Accessed May 2015 https://www.linkedin.com/groups/Autonomic-Road-Transport-Systems-3902895/about

Burke, Edmund K., Matthew Hyde, Graham Kendall, Gabriela Ochoa, Ender Özcan, and John R. Woodward. (2010) "A Classification of Hyper-Heuristic Approaches." In Handbook of Metaheuristics, edited by Michel Gendreau and Jean-Yves Potvin, 449–68. International Series in Operations Research & Management Science 146. Springer US, 2010. http://link.springer.com/chapter/10.1007/978-1-4419-1665-5_15.

Jamshidi, Mohammad. (2011), System of Systems Engineering: Innovations for the Twenty-First Century. John Wiley & Sons, 2011.

Hamdi, M, (2015). iMFV Autonomic Think Series: TRUST- the key to behaviour change. LinkedIn: https://www.linkedin.com/groups/iMFV-Autonomic-Think-Series-TRUST-2511997.S.5972820105216692227

Hamdi, M. and Mulvaney, D., Prioritised A* search in real-time elevator dispatching, (2007), Control Engineering Practice, Journal of IFAC, the International Federation of Automatic Control, Vol 15, issue 2, pp. 219-230, Feb 2007. ISSN 09670661

Hamdi, M., Mulvaney, D.J., (1998), "Simulation of Lift Passenger Systems and Modelling of Passenger Movements", International Journal of Elevator Engineering , 2 , April 1998, pp 1-18, ISSN: 1029 6646 .

Hamdi, M., (2015), "iMFV Autonomic Think Series: TRUST- the key to behaviour change", Accessed May 23, 2015.: https://www.linkedin.com/groups/Autonomic-Road-Transport-Systems-3902895/about

Kephart, J.O., and D.M. Chess. (2003) "The Vision of Autonomic Computing." Computer 36, no. 1 (January 2003): 41–50. doi:10.1109/MC.2003.1160055.

Laarabi, Mohamed Haitam, Azedine Boulmakoul, Roberto Sacile, and Emmanuel Garbolino. (2014) "A Scalable Communication Middleware for Real-Time Data Collection of Dangerous Goods Vehicle Activities." Transportation Research Part C: Emerging Technologies 48 (2014): 404–17.

Madureira, Ana Maria, Ivo Pereira, Nelson Sousa, Paulo Ávila, and João Bastos. "Autonomic computing for scheduling in manufacturing systems." (2009).

Misir, M., Verbeeck, K., De Causmaecker, P., and Berghe, G. V. (2010). Hyper-heuristics with a dynamic heuristic set for the home care scheduling problem. In Proceedings of the IEEE Congress on Evolutionary Computation (CEC 2010), pages 1–8. IEEE.

McCluskey, T. L., (2014), "Autonomic and Autonomous Systems", Accessed May 23, 2015.: https://www.linkedin.com/groups/Autonomic-Road-Transport-Systems-3902895/about

McCluskey, T. L. (2011) "A New COST Action: Autonomic Road Transport Support (ARTS) Systems." AISB Quarterly, no. 132 (September 2011): 4–5.

Milea, V., F. Frasincar, and U. Kaymak. (2012) "tOWL: A Temporal Web Ontology Language." IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics 42, no. 1 (February 2012): 268–81. doi:10.1109/TSMCB.2011.2162582.

Ochoa, G., Qu, R., and Burke, E. K. (2009). Analyzing the landscape of a graph based hyper-heuristic for timetabling problems. In Proceedings of the 11th Annual conference on Genetic and evolutionary computation (GECCO '09), pages 341–348, New York, NY, USA. ACM.

Ouelhadj, D. and Petrovic, S. (2008). A cooperative distributed Hyper-Heuristic framework for scheduling. In IEEE International Conference on Systems, Man and Cybernetics, 2008. SMC 2008, pages 2560–2565. IEEE.

Özcan, Ender, Mustafa Misir, Gabriela Ochoa, and Edmund K. Burke. (2010) "A Reinforcement Learning - Great-Deluge Hyper-Heuristic for Examination Timetabling:" International Journal of Applied Metaheuristic Computing 1, no. 1: 39–59.

Ross, P. (2005). Hyper-heuristics. In Burke, E. K. and Kendall, G., editors, Search Methodologies, pages 529–556. Springer US.