ISSN: 2186-8492, ISSN: 2186-8484 Print
Vol. 2 No. 3 August 2013

A MULTI-STAGE HEURISTIC APPROACH TO RESOURCE ALLOCATION (AMHARA) FOR AUTOMATED SCHEDULING

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ABSTRACT

This paper presents a practical Method for characterising, modelling and solving scheduling problems using a heuristic approach. The emphasis is on a heuristic methodology which has been adopted in developing the TRANSIM nurse allocation system. TRANSIM has been used in designing schedules in various schools of nursing in England and Australia. The methodology can be adopted for the purpose of automated scheduling in a variety of management and engineering applications.

Keywords: Heuristic, Resource Allocation, Scheduling

INTRODUCTION

Optimisation methods such as linear, integer, goal and dynamic programming and their derivatives have been used for scheduling. The majority of these techniques rely on mathematical formulation to describe the scheduling problem. Mathematically defined scheduling constraints are used to limit the search space. An objective function is formulated to optimise the allocation of resources within the confines of the constraints. In a real life situation, scheduling objectives are not always singularly aimed at optimising costs, profits or time. There are often many different and often quite subtle objectives to be met in the schedule. The capturing of these subtleties within a mathematical formulation can be an extremely difficult task (Nooriafshar, 1988).

The scheduling task is a problem of searching for the *possible* and *acceptable* solutions. This can be achieved by *generating* a schedule and *testing* it to see whether it meets the requirements.

The heuristic methodology presented in this paper (AMHARA) has been put to the test by applying it to the problem of nurse allocation to hospital wards.

The system (TRANSIM) developed for this application has been described in detail in (Nooriafshar, 1995).

The main purpose of this paper is to present the methodology which constitutes the inference engine of the nurse allocation system, as a resource allocation heuristic in management and engineering applications. It should be noted that this paper makes references to some of the classic literature in which the pioneers have laid the foundations of heuristic resource allocation. The methodology presented in this paper has its roots very firmly established in heuristics. Hence, it would be appropriate to define heuristics. Defined, 'heuristics are strategies that ignore information to make decisions faster, more frugally, and/or more

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accurately than more complex methods. " (Gigerezer and Gaissmeier, 2011: 453). Why are heuristics useful? One pair of researchers offers the following thoughts.

"Heuristics can be more accurate than more complex strategies even though they process less information (less-is-more effects). A heuristic is not good or bad, rational or irrational; its accuracy depends on the structure of the environment (ecological rationality). Heuristics are embodied and situated in the sense that they exploit core capacities of the brain and their success depends on the structure of the environment. They provide an alternative to stable traits, attitudes, preferences, and other internal explanations of behaviour. With sufficient experience, people learn to select proper heuristics. Decision making in organizations typically involves heuristics because the conditions for rational models rarely hold in an uncertain world. "(Gigerenzer & Gaissmaier, 2011: 474)

The following sections will provide definitions, concepts and procedures used in 'A Multi-stage Heuristic Approach to Resource Allocation' (AMHARA).

Defining and Characterising Scheduling Problems

AMHARA adopts the following definition for scheduling:

"We can describe scheduling as the allocation of *resources* to various *operations or areas* over a *period of time*, subject to a number of *constraints*, in order to *produce a product or provide a service*."

To expand on the above definition:

- **Resources** are defined as the entities which are to be scheduled. For instance, *ships, examinations, employees, students, jobs, etc.*
- **Operations or areas** are the facilities which receive the allocated entities. For instance, *ports, classrooms, training activities, shifts, machines, etc.*
- **Periods of time** is the time scale along which the allocation takes place. For example, the time periods could be *weeks, days, hours, etc.*
- **AMHARA** generalises the constraints as follows:
  - Sequence of Allocations for each resource
  - Allocation Duration for each area
  - Overloading/Underloading of areas under each Time Period

TIME PERIODS

RESOURCES		P1	P2	P3	--	Pt
	R1	a2	a6	--	--	--
	R2	a1	a5	--	--	--
	R3	a1	a4	a4	--	--
	--	--	--	--	--	--
	Rn	--	--	--	--	--

LEGEND:
Resources: R1, R2 .. Rn
Time Periods: P1, P2 .. Pt
Areas: a1, a2 .. am

Figure 1. Graphical representation of the main components

ISSN: 2186-8492, ISSN: 2186-8484 Print
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Figure 1 shows the main components and the three types of constraints used in AMHARA. For instance, area/operation a2 followed by area/operation a6 is a Sequence constraint for resource R1; resource R3 may require to be allocated for 2 Time Periods to area a4, this would be a Duration constraint; and as Figure 1 shows area a1 has an Overloading constraint of 2 resources under Time Period P1.

AMHARA adopts an approach similar to the classic Means Ends analysis of GPS by Ernst and Newell (1969), to produce a satisfactory solution.

In this type of approach, the problem starts at an initial state and ends at a final or goal state when the solution is found. This process is usually completed in a series of stages. So, it is not just a single transition from the initial stage to the goal stage – it is a multi-stage approach.

A typical analogy would be the game of chess, in which the objective is to place the opponent's king in a checkmate position in a series of moves starting from the initial board set-up.

SEARCHING METHODOLOGY AND PROCEDURES

AMHARA starts the search for a possible solution at Time Period 1 and as it finds suitable allocations for resources under each time period, it proceeds to the next level in the search space (the next time period). This process continues until the Time Periods (levels in the search space) are exhausted and appropriate allocations are made. It should be noted that selecting a resource could either be done sequentially, or a priority list could be used to select the next available resource. The latter would be more appropriate, as in some applications resources might have different characteristics. Figure 2 illustrates an outline flow diagram of the allocation method.

Working through an Example

To demonstrate how this heuristic methodology can be applied to scheduling, let us manually work through a hypothetical scheduling problem.

Let us assume that we wish to allocate resources A, B, C and D to two (2) different tasks, P and Q over five (5) time periods of 1, 2, 3, 4 and 5. The objective is to generate a schedule which satisfies the following rules:

1. There should be two (2) resources allocated to operations P and Q for each Time Period, except Time Period 3.
2. There should be one (1) resource allocated to operations P and Q in Time Period 3.
3. P followed by P (PP) and Q followed by Q (QQ) are invalid sequences.
4. Resource A is an important resource, and it has the highest (first) priority.

It should be noted that in some applications, it may be necessary to relax one or more of the generic constraints. For instance, this simple problem contains 'Overloading' and 'Sequence' constraints, but the 'Duration' constraint is relaxed.

Solution

Let a_{ij} represent the allocation variable which can take values of P and Q. Constraints 1 and 2 above, can be represented as follows:

$\Sigma a_{i1} = 2P+2Q$, $\Sigma a_{i2} = 2P+2Q$, (1)

$\Sigma a_{i4} = 2P+2Q$, $\Sigma a_{i5} = 2P+2Q$ and

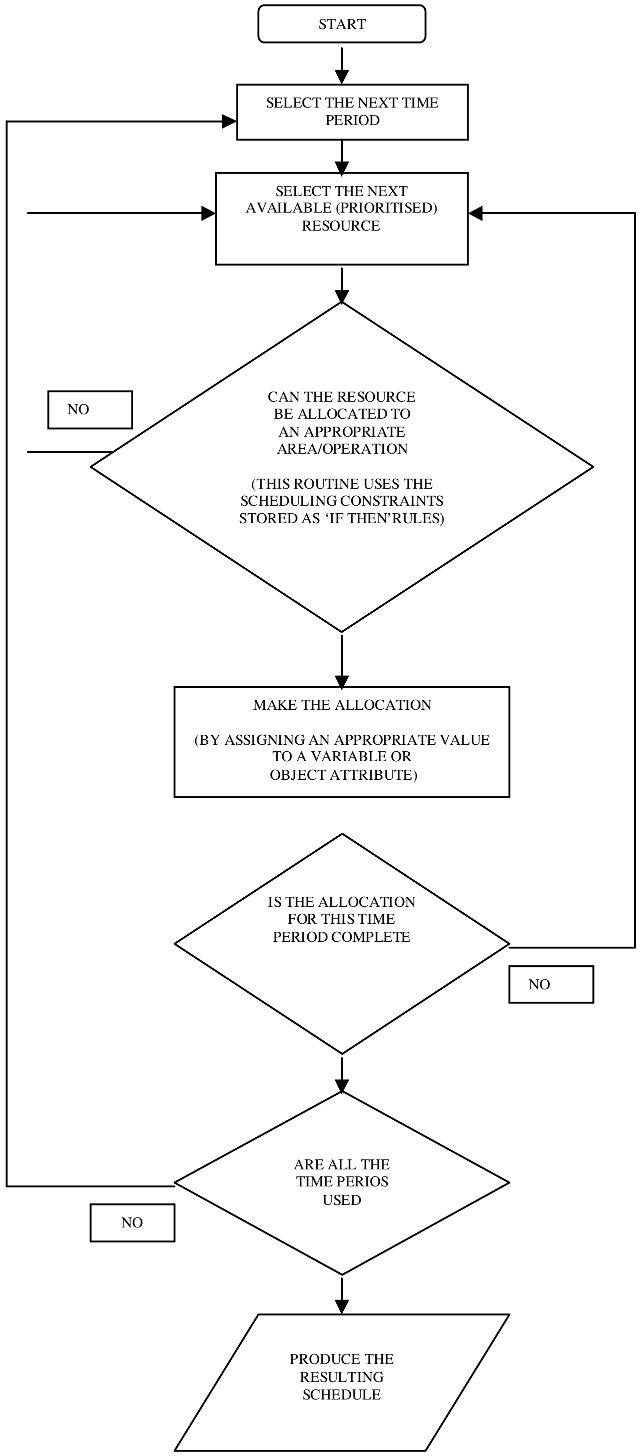

Figure 2. An outline flow diagram of the allocation method

$\Sigma ai3 = 1P+1Q$ (2)

where i = 1 to n [n = number of resources (4)]

j = 1 to m [m = number of time periods (5)]

And the valid sequencing constraints are:

ISSN: 2186-8492, ISSN: 2186-8484 Print
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P followed by Q (PQ), Q followed by P (QP), anything but P followed by P (-P), anything but Q followed by Q (-Q), and P followed by anything but P (P-) and Q followed by anything but Q (Q-).

Applying the heuristic procedures explained, we may proceed as follows:

I. Start with an initial state. See Figure 3.

II. Start the next Time Period (Time Period 1).

III. Select the next available (prioritised) resource. It would be A in this case.

IV. Can the resource be allocated to an appropriate operation? Yes, we can allocate it to either P or Q without violating any rules (1, 2 or 3). Let us select P.

V. Make the allocation by assigning an appropriate value to the allocation variable $a_{ij.}$ Therefore, P can be assigned to a_{11}.

VI. Is the allocation for this time period complete? No, so repeat steps iii to vi, but this time, the next available resource would be either B, C or D. This process would be repeated until all resources are selected from the list. The results would produce the possible intermediate states. See Figures 4 and 5. Note that when resources have equal priorities, they can be selected on a sequential basis.

VII. Are all the time periods used? No, we are still in time period (stage) 1. Therefore, go back to step ii and repeat the whole process with the incremented stage until all time periods are used.

VIII. Produce the resulting schedule and end the procedure. This would be a possible goal state. See Figure 6.

TIME PERIODS

RESOURCES	1	2	3	4	5
A	--	--	--	--	--
B	--	--	--	--	--
C	--	--	--	--	--
D	--	--	--	--	--
P¹	2	2	1	2	2
Q¹	2	2	1	2	2

P¹ represents maximum allocations to Operation P Q¹ represents maximum allocations to Operation Q

Figure 3. Stage 0, the initial state

TIME PERIODS

RESOURCES	1	2	3	4	5
A	P	--	--	--	--
B	P	--	--	--	--
C	Q	--	--	--	--
D	Q	--	--	--	--
P¹	2	2	1	2	2
Q¹	2	2	1	2	2

P¹ represents maximum allocations to Operation P Q¹ represents maximum allocations to Operation Q

Figure 4. Stage 1, a possible intermediate state

TIME PERIODS

R	1	2	3	4	5
A	P →	Q	--	--	--
B	P →	Q	--	--	--
C	Q →	P	--	--	--
D	Q →	P	--	--	--
P¹	2	2	1	2	2
Q¹	2	2	1	2	2

P¹ represents maximum allocations to Operation P Q¹ represents maximum allocations to Operation Q

Figure 5. Stage 2, a possible intermediate state

TIME PERIODS

R	1	2	3	4	5
A	P →	Q →	P →	Q →	P
B	P →	Q →	-- →	P →	Q
C	Q →	P →	Q →	P →	Q
D	Q →	P →	-- →	Q →	P
P¹	2	2	1	2	2
Q¹	2	2	1	2	2

P¹ represents maximum allocations to Operation P Q¹ represents maximum allocations to Operation Q

Figure 6. Stage 3, a possible goal state

As we can see, the general principle is very similar to that of Dynamic Programming as described in the classic paper by Bellman (1957). In Dynamic Programming, the problem is divided into a number of sub-problems (stages); these stages are related to each other by a recursive relationship. The objective is to find optimal solutions for each stage until the final stage is reached which would determine the overall solution. Unlike Dynamic Programming which approaches the problem either from the end or the beginning, Multi-stage Heuristic approaches the problem in a 'forward chaining' manner. In Multi-stage Heuristic scheduling, the stages are related to each other by the constraints; hence, the decision for each stage is not made in isolation.

CONCLUSIONS AND FUTURE DEVELOPMENTS

Scheduling, traditionally has been tackled using quantitative techniques, such as Linear Programming, Critical Path Methods, Johnsons Algorithm and its extension and so on. These techniques are basically *algorithmic*, and their main objective is to find an optimal solution.

The subject of scheduling and the *heuristic* approaches to solving it have received a great deal of attention in the AI/expert systems' community, and their literature, at an international level. In a heuristic approach to scheduling, the objective is to find a functional solution, rather than an optimal one, as in other applications such as the Nearest Neighbour Heuristic by Golden et al (1080).

The majority of researchers in this area regard scheduling as a complex task and attribute this complexity to it being *combinatorially explosive*. The fact that in a scheduling problem there may be a number of conflicting objectives to meet, also contribute to the complexities.

This paper approaches the problem of scheduling from a different angle. Its main objective is to put forward a general purpose solution to this problem or, to be more precise, a *Multi-stage Heuristic Approach to Resource Allocation* for modelling and solving different scheduling problems. The applicability of this heuristic approach to scheduling has been demonstrated by employing it in design of the TRANSIM scheduling system.

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