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The Multi Crane Scheduling Problem: A Comparison Between Genetic Algorithm and Neural Network Approaches based on Simulation Modeling

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Prof. Roberto Revetria, Ph.D. Resume

1998 – Mechanical Engineering Degree, summa cum laude, University of Genoa

2001 – Ph.D. in Industrial Engineering, University of Parma

2004 – Associate Professor, University of Genoa

2010 – Full Professor, University of Genoa

Area of expertise: construction of computer-aided analysis models and tools brought him to develop complex software using multipurpose and dedicated (Simula, AnyLogic, Flexsim, Automod, Simul8, ESL, GPSS/H, Arena, Witness, Plant Simulation, Powersim, iThink/Stella, VenSim, Berkeley Madonna) simulation tools. He makes use and develops models in virtual reality.

Involved in many top-level management **training courses**: Risk Management, Decision Support Systems and Project Management for Healthcare.

Editorial Board of the following International Journals:

- Journal of Engineering, Computing & Architecture
- Journal of Computer Science, Informatics and Electrical Engineering
- Journal of Mechanical, Aerospace and Industrial Engineering
- International Journal of Information Systems and Supply Chain Management
- JSE, Journal of Security Engineering
- European Journal of Operative Research

Introduction

To move materials, particularly heavy or bulky ones, in warehouses, **bridge cranes** are often used. These frequently share runway girders. The presence of more than one overhead bridge crane sharing the same runway girders, virtually over the same served area, represents an **enormous advantage in terms of efficiency for the operations**, but also markedly **increases the complexity** of job scheduling, with relevant consequences for plant and workers’ safety.

To date, the management of overhead traveling cranes is still done manually for many reasons, mainly related to the safety and extreme conditions of these systems such as temperature, dust, and the handling of generally heavy or unwieldy objects.

Nonetheless, the latest developments in the field of sensors and the implementation of interventions today invite exploration of **completely automatic** management of the movement of the bridge cranes, in particular applied in the **park area.**

Crane scheduling as an optimization problem

The scheduling of overhead crane movements is an optimization problem, given the data of a list of jobs (withdrawal-deposit); the goal is to find the best sequence with the assignment of single jobs to complete all the jobs in the shortest possible time.

The planning of the bridge crane has become the key to any production procedure and represents a decisive factor to ensure the production process operates with stability, reliability, and high efficiency in the workshop and solve spatial conflicts between cranes.

It is, therefore, necessary to study a method that could simultaneously and effectively eliminate the spatial and temporal conflict between cranes.

Finding optimal solutions to planning problems is generally a difficult proposition, entailing combinatorial optimization and often being strongly **nondeterministic polynomial** (**NP**).

Proposed Approach

Comparison between two different approaches is proposed to be analyzed in parallel on a test frame offered by a simulation model:

1) Application of a wizard for optimization based on **Genetic Algorithms**
2) **Machine Learning** for piloting the multi crane by a Neural Network

The comparison is **currently still on a qualitative level** and this paper proposes a test frame for further performance comparisons. Quantitative results from the Genetic Algorithm solution are shown, while hypotheses on the Neural Network approach results are described, taken from general evaluation and results by commercial solutions.

Literature Review

Several scholars used and tested different solution for improving the **Multi Crane Scheduling Problem:**

- **Zäpfel et al.** presented new ideas with the aim of increasing the efficiency (minimizing the processing time) of the steel supply chain, by improving warehouse management, concerning the handling of different types of steel coils with the help of overhead cranes subject to time constraints using nonlinear optimization.
- **Graunke et al.** studied the sequencing problem that was based on a multi-crane programming problem in a coils warehouse. Indeed, for problems on a larger scale, the heuristic algorithm generates quick, robust and acceptable solutions. In this view, the genetic algorithms were used for the optimization of the integrated programming of overhead cranes and storage platforms at the automated container terminals. This article introduced a genetic algorithm capable of performing integrated programming of quay cranes, automated guided vehicles and handling platforms; in particular, this work is oriented towards container terminal applications.

- **Xie et al.** consider a multi-crane programming problem commonly encountered in real warehouse operations in steel companies' warehouses of steel coils. To clearly describe the problem studied, it was first formulated as a mixed Model of Integer Linear Programming (MILP); after which some feasible and optimal properties were identified for the assignment of the bridge cranes to avoid collisions. Since a particular case of the problem has proved to be strongly NP-hard, a heuristic algorithm has also been proposed to solve the aforementioned problem efficiently. In the heuristic algorithm program, for each crane, a detailed sequence specifies the order of all the necessary coils and the position of each block coil to be repositioned.
- **Ma et al.** present a method of simulating crane programming in the steelworks workshop based on the Multi-Agent System (MAS). The scheduling system mainly includes groups of agents for overhead cranes, groups of agents for workstations and agents for managing coordination. MAS can decompose a complex and large system into many simple agents that have a simple structure, can interact with each other and can be easily managed. The research shows that the simulation method based on the MAS is feasible and can meet the demand of the bridge crane in a timely and effective way. Furthermore, it can reduce the average transit time of materials and also describe the characteristics of the overhead cranes in the steel mill efficiently

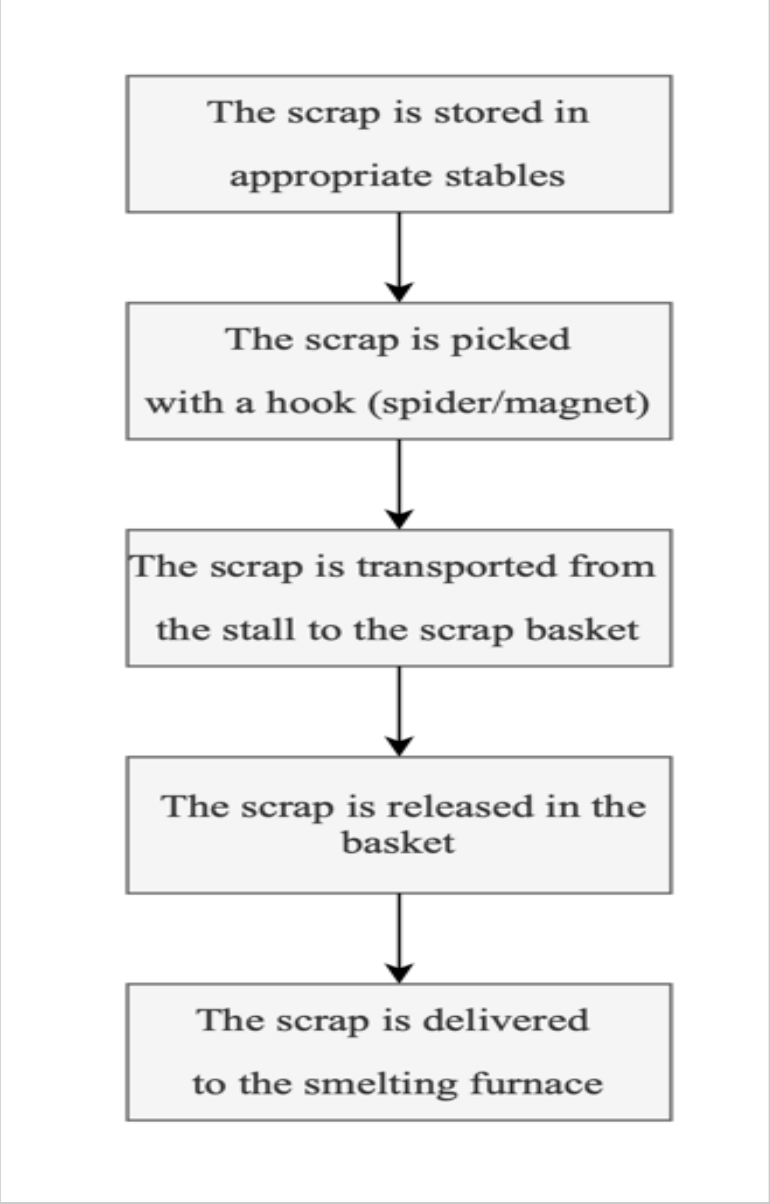
- **Lim at al.** examine the programming of overhead cranes for ports through the Tabu Search (TS) method, a search procedure that proceeds iteratively from one solution to another by moving to a “neighborhood space” with the help of adaptive memory. Probabilistic Search for Tabu (PTS) is a variant of the basic TS, which places more emphasis on randomization than the basic TS. From the experiments, the comparison and the above analysis, it is, therefore, believed that the Tabu Probabilistic Research is a good heuristic method to find good solutions to the programming problem of the bridge cranes.
- The **use of Machine Learning** and **AI** in multi-crane driving is as yet a task unconsolidated in the literature, although early studies and commercial solutions based on model simulation are appearing on the market.
- On the contrary, job scheduling problems in manufacturing have been studied via Machine Learning for many years. Results from Jain et al. and Weckman et al. are expressions of specific system architectures in this direction have been evaluated. Their results emphasize that the solution through a Neural Network scheduler provides performances very close to a Genetic Algorithm scheduler.

General Description

- The steel plant is divided into several bays and, in this elaboration, we have focused on the analysis of the scrap park which represents the area where the material is stored awaiting loading into the kilns.
- The shed analyzed is characterized by several stalls (sheet pantograph, turning, pre-reduced, naval, etc.) and each of these represents a possible starting point for the scrap.
- There are three preparation points where the scrap baskets are then prepared.
- To move, after loading the scrap in the various stalls, and unloading it subsequently in the baskets, there are three overhead traveling cranes that travel on a single track.
- The real dimensions for the shed are the length of runway (213m) and the respective width of runway (63m)

In the scrap park, overhead cranes must manage mainly:

- The supply of scrap, moving it from trucks/flights to stacks in dedicated bays,
- Loading the scrap, moving it from the stacks to the baskets (or conveyor belts) which then deliver the scrap to the melting furnace, following a suitable and predetermined succession by type.
- Three overhead cranes share the same runways and are engaged by the simulation scheduling system. The task of the system is to provide scrap materials to specific baskets, starting from different sources according to a specific recipe, needed for the final product (steel type) to be produced. The overall process flowchart is shown in this slide.



Simulation Model

- The simulation software used is Tecnomatix Plant Simulation.
- The real features of the shed have been attributed to the model frame, so the geometric scale is one-to-one relative versus the model.
- An initialization function called at the beginning of the simulation loads into a column of a data table all the portal cranes desired and creates their frame logic and 3D counterparts.
- The portals need other functions to take the mobile unit (hoist load), then the object, and take it from the originating station to the arrival station.

- The scrap park is made up of several stations, so there are more starting points where the scrap is available. These areas are modelled as buffers with an infinite capacity assigned. A structure is therefore built in and the starting points are arranged in matrix format.
- The same procedure is used to represent the scrap baskets which, unlike the scrap pick-up points, are connected to a drain block and then are to be deleted. The base is to create recipes and a function that reads recipes data from a table is provided.
- This table consists of two columns: a first column where each row represents a location, i.e. a scrap pick-up point (i.e. the buffers), and a second column that contains a number, which indicates the number of catches that must be done in that location.

- A queue is created for each portal crane with the following features:
  - A function to take the first object of the queue, which is then removed;
  - A function which allows the analyst to add an object;
  - A function to take the first object at the top without removing it; therefore, the analyst can examine it as often as necessary.
- The recipes are provided for more than one basket depending on the type of steel to be made. The scrap pick-up location and the number of pick-up tasks for each location will be provided for each recipe.
- **Travel Salesman Problem can be compared to the scheduling problem for the loading of scrap baskets** in the sense that there is a sequence of operations to be carried out, specifically the movements with the bridge crane, with the difference that the sum of the times necessary to load the baskets must be minimized, in contrast to minimizing the sum of the distances to be covered.

Genetic Algorithm Solution

Genetic Algorithm is an efficient solution because the optimization task at hand has many variants of different solutions.

In the specific case, a GA wizard is instantiated to integrate genetic algorithms into the test frame of the simulation model.

Input and Output of the optimizer

OrderID	*RecipeID*	*Basket_Seq*	*StartTime*	*EndTime*	*DueDate*	*Delay*	*Elapsed*
9	Recipe4	Basket1	2018/01/01 00:02:38	2018/01/01 00:28:41	2018/01/01 01:00:00	0.00	26.04
8	Recipe1	Basket3	2018/01/01 00:00:56	2018/01/01 01:27:15	2018/01/01 01:10:00	17.25	86.31
4	Recipe3	Basket1	2018/01/01 00:33:21	2018/01/01 02:06:48	2018/01/01 02:30:00	0.00	93.45
6	Recipe1	Basket1	2018/01/01 02:10:31	2018/01/01 03:38:04	2018/01/01 03:40:00	0.00	87.56
3	Recipe2	Basket3	2018/01/01 01:31:43	2018/01/01 03:12:17	2018/01/01 04:55:00	0.00	100.56
5	Recipe2	Basket1	2018/01/01 03:39:45	2018/01/01 05:51:18	2018/01/01 05:40:00	11.30	131.55
1	Recipe4	Basket3	2018/01/01 03:16:55	2018/01/01 04:46:51	2018/01/01 04:50:00	0.00	89.93
10	Recipe4	Basket2	2018/01/01 00:01:25	2018/01/01 00:19:17	2018/01/01 00:40:00	0.00	17.87
2	Recipe2	Basket2	2018/01/01 01:25:52	2018/01/01 01:31:11	2018/01/01 01:35:00	0.00	65.32
7	Recipe1	Basket2	2018/01/01 01:35:28	2018/01/01 02:43:12	2018/01/01 02:45:00	0.00	67.72

- **Inputs:** OrderID, ReceipeID, Basket_Seq, StartTime, EndTime, DueDate
- **Outputs**: Delay, Elapsed

GA APPROACH

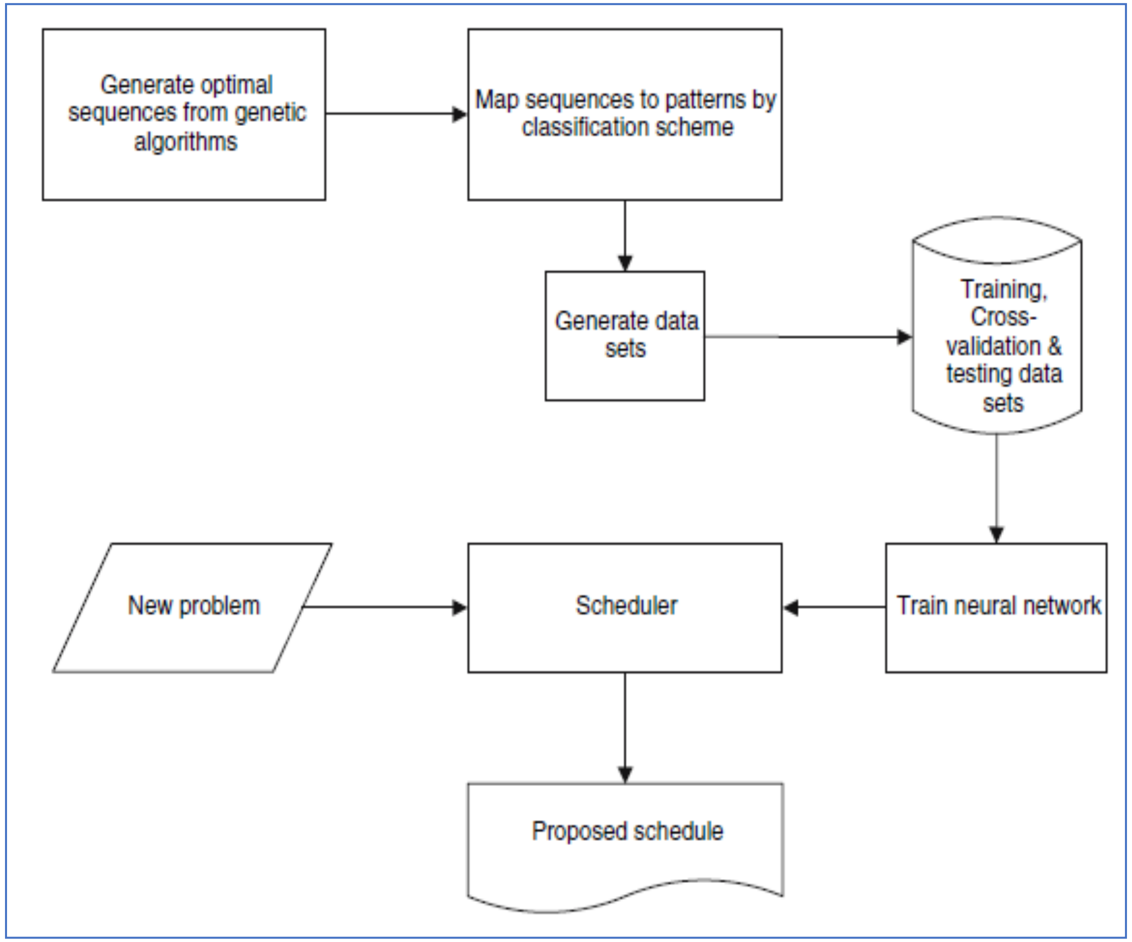
- The solutions generated by the Genetic Algorithms wizard object are passed to the simulation model, which in turn will be configured accordingly.
- At the end of the simulation run, the test frame model transfers the resulting fitness value to the GA wizard object.
- When the Genetic Algorithms creates individuals, who define the same parameterization, the GA wizard recognizes it and uses the fitness values of the individuals already evaluated.
- Performing optimization therefore does not waste additional time for multiple assessments of an individual.

GA ADVANTAGES

1. compared to classical methods genetic algorithms are immune to the number of variables. Classical numerical methods are often imprecise due to rounding errors which increase rapidly as the number of variables increases.
2. that the method of finding the solution does not presuppose any type of linearity of the problem, so it is also possible to face problems in which one or more non-linearities exist, possibly also in the form of constraints.

Neural Network Solution

The NN scheduler will be created following the below system architecture:



The Neural Network suitable for this aim is the **Multi-Layer Perceptron (MLP)** with **one hidden layer** and trained using a **back-propagation** algorithm. Regarding the simulation model, the test frame will be implemented with the following scheme:

- Creation of a connection between the model and the external neural network, to be developed on a software-specific platform (data must be collected continuously in the simulations before specified actions);
- Use of the model test frame to test the NN training algorithm;
- Testing the NN driving system for cranes on the same data set used for the GA solutions.

Genetic Algorithm Results

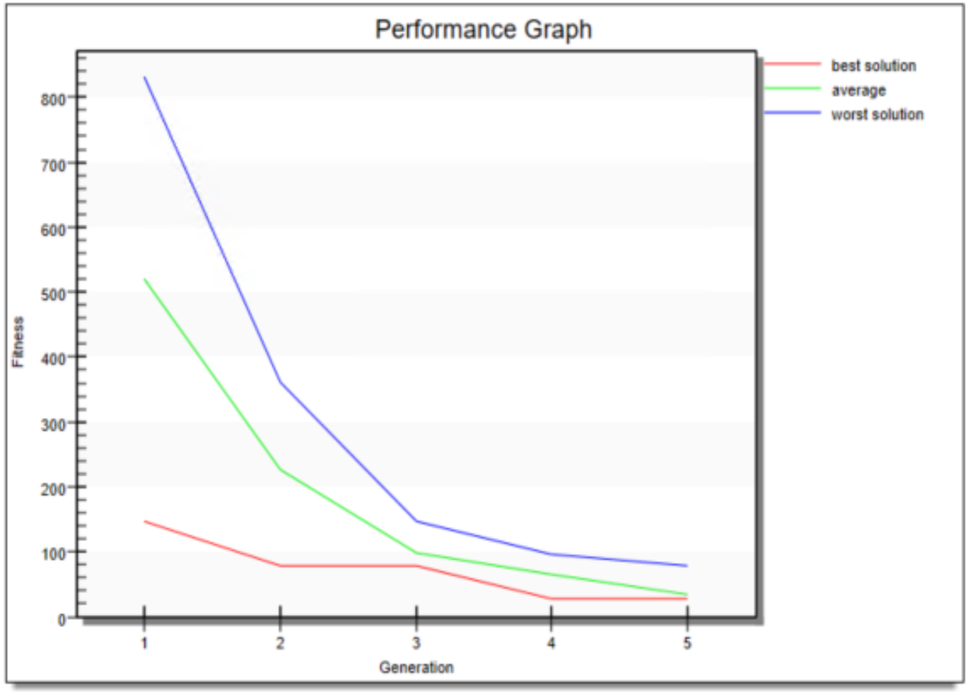
The solution represents the **best sequence of operations that minimize the objective function** which is intended as the sum of process and delay times contained in the column *Delay.* Intuitively, the shorter the delays, the better the configuration obtained.

The objective function, also called the **fitness function**, is the sum of the *Delays* and the minimum is obtained for Generation Four which reaches a value of roughly 28.55 (red curve next slide).

To reach the optimal value, **15 generations with 20 individuals per population and five generations per individual** have been chosen empirically.

Genetic Algorithm Solution

Fitness function trend for different solutions



Best individual For Generation 4

Individual	Fitness	Chromosomes	Observations
Gen 4 Ind 3	28.55409	Chrom 1	Fitness 53
Gen 4 Ind 6	28.55409	Chrom 1	Fitness 56
Gen 2 Ind 8	78.70279	Chrom 1	Fitness 18
Gen 3 Ind 5	78.70279	Chrom 1	Fitness 35
Gen 4 Ind 2	78.70279	Chrom 1	Fitness 52

Machine Learning evaluation

In the hypothesis of this paper, performances very close to GA ones are expected with the neural network approach. A peculiar expected result, to be quantitatively inspected, is the capability of the NN scheduler to quickly react to scenarios never seen before.

From commercial feedback collected so far, a performance gain of 50% to 70% is expected, compared to other optimization methods

Conclusions

- The use of Genetic Algorithms has proven to be a good method for solving NP-hard problems, hence also the problem related to the scheduling of the movements of the overhead cranes for loading scrap baskets in the steel industry.
- Certainly, of fundamental importance is the creation of the model because in order to avoid errors or to avoid obtaining results that differ too much from reality, it is necessary to make the virtual model as equivalent as possible to the real one, creating a Digital Twin.
- This overhead crane scheduling problem has received attention in the literature and different methods have been used (network flow model, Tabu research, MAS based), but the performance of the Genetic Algorithms is considered the best. Even in the case of multiple gantries, the method based on Genetic Algorithms provides a solution to improve their efficiency and the introduction of the GA Wizard object improves the preparation times of the scrap baskets for melting furnaces; consequently, also an improvement of the overall performance of the steel company is achieved.
- The most important achievement of the paper is the development of a challenging test frame to compare GA results with the ones expected by the use of a neural network technique.
- Further studies will complete the comparison proposed.

Thanks for your attention!