Uncertainty in Real-World Steel Stacking Problems

Andreas Beham
Heuristic and Evolutionary Algorithms Laboratory,
[1]University of Applied Sciences Upper Austria,
Hagenberg, Austria
[2]Institute for Formal Models and Verification, Johannes Kepler University, Linz, Austria
andreas.beham@fh-ooe.at

Sebastian Raggl
Heuristic and Evolutionary Algorithms Laboratory,
University of Applied Sciences Upper Austria,
Hagenberg, Austria
sebastian.raggl@fh-ooe.at

Stefan Wagner
Heuristic and Evolutionary Algorithms Laboratory,
University of Applied Sciences Upper Austria,
Hagenberg, Austria
stefan.wagner@fh-ooe.at

Michael Affenzeller
Heuristic and Evolutionary Algorithms Laboratory,
[1]University of Applied Sciences Upper Austria,
Hagenberg, Austria
[2]Institute for Formal Models and Verification, Johannes Kepler University, Linz, Austria
michael.affenzeller@fh-ooe.at

ABSTRACT

In this position paper we describe challenges related to uncertainty handling when solving stacking problems within storage zones in the steel production value chain. Manipulations in those zones are often relocations of materials performed with gantry cranes. Thereby the crane operators themselves or dispatchers constantly solve a complex stacking problem with the goal of minimizing relocation effort under constraints to adhere to various time windows and to satisfy quality demands.

CCS CONCEPTS

• **Computing methodologies → Planning under uncertainty**;
• **Applied computing** → *Command and control*;

KEYWORDS

stacking, steel logistics, uncertainty

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1 INTRODUCTION

The steel stacking problem (SSP) [12] is an extension to the stacking problem (SP) [13] which is based on the block relocation problem (BRP) [9]. In the classical BRP the problem environment consists of stacks and blocks. Blocks have an associated unique sequence number and are distributed among stacks in vertical positions. Only the topmost block of each stack may be relocated and each relocation needs to be completed before a new one can be started. Blocks can only be put on empty stacks, at the top of another stack, or at the handover stack. Blocks at the handover stack may not be relocated again. Stacks may have a maximum height. The solution to the BRP is a sequence of relocations such that all blocks are put on the handover stack in ascending order of their sequence number. In the *restricted* BRP variant, only necessary relocations may be made; these concern only blocks above the next block in sequence. There are multiple integer programming formulations for the BRP that are able to find exact solutions for small instances [11, 17]. Several tree-search based approaches have been proposed for example Branch&Bound [6, 15], A* search [19], rake search [16] and beam search [2]. They all use sophisticated heuristics to speed up the search. There is a BRP variant called dynamic BRP where in addition to the delivery sequence an arrival sequence specified and blocks have to enter and leave the yard in accordance with those sequences [1]. The stacking problem extends the dynamic BRP in that it introduces a source and associates a time window (release, due) to each block that describes its earliest availability at the source and its latest relocation to the handover [13].

The SSP redefines a block to be a material, i.e., slab, coil, bloom, sheet, etc., which gains additional attributes such as temperature, length, width, height, and weight that are relevant to a number of stacking constraints [12]. In the SSP *two* time windows are associated to each material as both the source and handover need to be serviced within a time window. Sources may be a continuous process such as a caster, while handover is often performed by loading onto pallets, waggons, or ships. Crane movements are non-instanteneous, however a relaxed formulation can be created where the time windows govern only the order of operations [13]. An overview of the system is given in Figure 1 showing the involved entities. Even quality assurance (QA) has to be taken into account, though as an environmental factor that is outside the control of this problem, yet QA has a strong influence on the order of operations.

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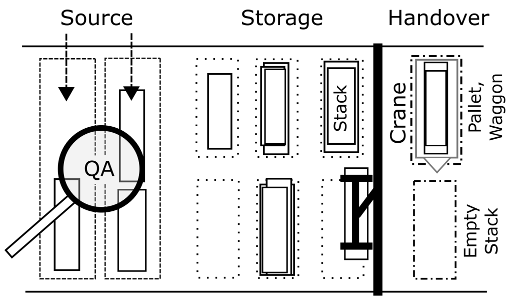

Figure 1: Top view of a steel stacking environment.

In previous works, different kind of uncertainties have been adressed. For example the influence of the uncertain weight of containers are considered in a port application was investigated [8]. Uncertainties in the handover priorities are modeled in three different ways in the literature. In the online BRP only the block that has to be retrieved next is known and the order of all other blocks is considered totally unknown. In this setting a leveling heuristic can be used, which has a known competitive ratio and good performance in practise [18]. Alternatively if the exact retrieval order is not uncertain but time windows for the departure are known this information can be used to improve uppon the pure online case [10]. In the stochastic BRP the retrieval order is again determined online but the distribution of possible orderings is known. A recent study investigates the case where blocks are assigned to batches with fixed and known retrieval order, but where the retrieval order within a batch is random and determined online [7].

The BRP has a single variable per block, namely the retieval priority, and even there multiple forms of uncertainty have been identified. SSPs have many more variables and every one of them can be subject to uncertainties. This paper aims to give an overview of the uncertainties encountered when solving real-world SSPs since this has not been covered in the literature.

2 STEEL STACKING IN AN UNCERTAIN ENVIRONMENT

Steel storage zones are highly dynamic environments. Temperatures have an important influence on product quality and cool down processes are often only approximated by software models. Production processes are monitored by quality assurance (QA) systems and production variances trigger approval processes regarding the future path of the product. In the following we aim to list and categorize the most important sources of uncertainties. The first two categories relate to environmental uncertainties and "design parameter tolerances" [3], which however is here described as *implementation uncertainty*. The last category lists events that have a sudden impact on the problem and its solutions.

2.1 Environmental Uncertainty

In applying steel stacking solutions to real-world environments we note the following environmental uncertainties that must be addressed:

E1 Manipulation time of gantry cranes are stochastic
E2 Source and handover time windows are uncertain
E3 Handover time windows are interdependent
E4 Maintenance and pauses introduce uncertain delays
E5 Material properties are uncertain

Uncertainty *E1* describes the manipulation time as a random variable. It is influenced by independent variations in movement speed, pick-up and drop-off time. Additionally, depedenent influences are due to inspections, manual labelings, and situations in which the target is blocked by operations of another crane on the same track. More importantly, uncertainty *E2* means that both the ready time and due date of the involved time windows at the source and handover are uncertain. Casting speed changes and labeling might fail, pallets or waggons at the handover may be delayed or broken. We also observe an interdependence among subsequent time windows as desribed in uncertainty *E3*. This results in a chain of joint probabilities. For instance, serving a handover rather late may also delay the next time window. Uncertainty *E4* describes that the exact start time and duration of maintenance windows and also of pauses or handovers between operators are not known in advance. Uncertainty *E5* describes that material properties that are calculated by models such as temperature are highly uncertain. This introduces growing uncertainties during the planning window. In relation to this, steel composition may or may not be within tolerances, which introduces alternatives in handover time windows as the future path of the product may change.

2.2 Implementation Uncertainty

Solution implementation is achieved by performing the optimized relocations in sequence within the allotted time slots. However, a number of uncertainties exist:

I1 Relocations may not be completed within the given time slot
I2 Relocations may involve wrong materials or locations
I3 Relocations may become invalid

Delays may be introduced by having to wait for the material source or the handover or by crane movements taking longer than planned. Such delays may accumulate and may lead to due dates being missed as described in uncertainty *I1*. The presence of uncertainty *I2* is explained by erroneous implementation of the solution. The reasons are a mismatch of the state in the information system and the real world and errors of the crane operator. Finally, uncertainty *I3* can be observed when dynamic events lead to situations where a certain relocation cannot or must not be attempted anymore. For instance, when the material assigned to a certain handover window has changed.

2.3 Dynamic and Disruptive Changes

In the last category, we list disruptive events that require reaction or proactive handling, e.g., by considering their appearance as an alternative scenario.

D1 Break-downs of cranes, sources, and handovers
D2 Stacks are unavailable
D3 Priorities change and express orders are introduced
D4 Handover material is changed
D5 Materials are not in the expected position

Naturally, all machinery may break down abruptly and without notice as given by dynamic *D1*. In addition, stacks may also become unavailable on short notice (*D2*), for instance to perform construction or maintenance works. Dynamic *D3* describes that the handover sequence may change, for instance due to express orders that are introduced and require immediate reaction. As it has been mentioned, quality defects may be detected during relocation. The originally planned material may be postponed and a substitute is selected. Dynamic *D4* describes such a situation. Grave situations generally arise when the real-world system state deviates from the information system state. A particularly bad case is when material is in a different position. Dynamic *D5* describes a rare event, but with severe consequences.

3 APPLICATION OF EVOLUTIONARY ALGORITHMS

Many successful methods are based on branch & bound [15]. Evolutionary methods have not received so much attention, and their application is impeded because constructive approaches have been found to be highly suitable. The perturbation of intermediate relocations in a stacking solution typically invalidates subsequent relocations. First approaches of improvement heuristics thus optimized the decisions of an underlying constructive heuristic by modifying its stepwise priorities of a restricted BRP [14]. An interesting research achievement was recently made for the unrestricted BRP in that an efficient neighborhood for a complete solution was defined and subsequently a local-search based improvement heuristic was introduced [5]. Such a neighborhood may be used as part of a mutation operator.

We perceive two developments that may make evolutionary algorithms more attractive. First, an advantage of evolutionary algorithms is their black-box nature. Evolutionary algorithms can be applied to different objectives more easily in comparison to branch & bound that depend on the strength of the lower bound. For instance, reducing the traveled distance of cranes, for which lower bounds are weaker, has received some attention and is of high practical relevance [4]. In addition, encoding uncertainties in the objective may be more easily achieved with a black-box algorithm. Second, considering dynamic events as they arise in most or any real-world application, a quick reaction is demanded. While pure construction heuristics are still fast, their performance is often significantly worse than that of a more elaborate tree search. The latter however has to be restarted entirely and takes time. Evolutionary algorithms however may not need to be restarted entirely and improve the amended solutions continuously and potentially in an open ended approach.

4 CONCLUSIONS

We have categorized and discussed uncertainty in real-world steel stacking environments and discussed the potentials of applying evolutionary algorithms to stacking problems with uncertainties. There is promising research on integrating the handling of uncertainties into models and solvers for the BRP, but for the SSP there is a significant research gap. In the future we plan to include these uncertainties in models and handle dynamic events in a continued an open ended algorithm.

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