The generalized sequential ordering problem for laser cutting toolpath generation

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In toolpath generation for laser cutting, one tries to find the shortest path that cuts all required edges and does not violate precedence constraints. These constraints can originate from three different sources: islands, common cuts, and heat conduction.

Islands occur when a contour is completely surrounded by another contour, as in the case when openings have to be cut in workpieces or as a side effect of the nesting of different pieces on one sheet. The precedence relation originates from the fact that the inner contour has to be cut before the outer contour is cut. Otherwise, the part is no longer attached to the rest of the sheet and might move, leading to inaccuracies. Hence, all edges of the inner contour have to be cut before the last edge of the outer contour is cut.

Common edges are formed during the nesting process. Two parts are occasionally placed next to each other in such a way that only one edge needs to be cut instead of two edges. The edge common to the two original contours needs to be cut before the surrounding contour (created by merging the two contours of which the common edge is part of) is cut. In other words, the common edge needs to be cut before the last edge of the surrounding merged contour is cut.

Heat conduction through the metal plate imposes atypical precedence constraints. Consider two adjacent edges i and j with a small opening angle in between. Due to the preheating effect of the cutting of the other edges on the plate and the actual cutting of edge i, the accumulated heat at the corner between i and j can be higher than a critical temperature when starting to cut edge j. This could cause the corner to show quality deterioration or even burn off. In order to avoid this, after cutting edge i, the laser has to cut a number of edges sufficiently far away, as to allow cooling of edge j.

We propose to model this problem of generating toolpaths for sheet metal laser cutting as a more general case of the generalized traveling salesperson problem (GTSP) [2] and the sequential ordering problem (SOP)[1]. In the generalized traveling salesperson problem, cities are grouped into districts, and the salesperson needs to find the shortest route to visit exactly one city of each district. The sequential ordering problem, is a traveling salesperson problem, where precedence

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constraints exist between cities e.g. city i needs to be visited (not necessarily immediately) before city j is visited. The generalized sequential ordering problem (GSOP) can then be described as a GTSP with precedence constraints between cities and/or districts.

An LP formulation of the GSOP taking into account the three kinds of precedence constraints described above is proposed. The LP is a basic model which does not yet take into account all problems that can be associated with sheet metal laser cutting. All-round toolpath generation models will also need to take following side-constraints into consideration: *skeleton cuts, plate edge, piercing points, bridges, lead-in cuts, laser head collisions, clamps, plate repositioning* and *imposed path patterns*. Later on, these constraints can be added to the model one by one.

References

[1] L F Escudero. An Inexact Algorithm for the Sequential Ordering Problem. *European Journal of Operational Research*, 37:232–253, 1988.

[2] G Laporte and Y Nobert. Generalized Travelling Salesman Problem Through n Sets of Nodes: An Integer Programming Approach. *Information Systems & Operational Research*, 21:61–75, 1983.