Manufacturing Logistics Optimization using the SPECTER Task Planner: A Shoe Manufacturing Logistics Case Study

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Abstract. This paper presents an application of SPECTER task planner for shoe manufacturing logistics. In this case study we propose an abstract model of the work flow of a shoe manufacturing company taking into account: i) the workflow stages; ii) the time costs (i.e. a machine operation, products time construction, worker transitions between work-cells); and iii) the agents involved in the production line (such as machines, humans, materials, products etc.). Based on the derived abstraction, optimal solutions are provided for utilizing 1, 2 or 3 workers in the production line. The paper validates the modeling power of the SPECTER framework, while demonstrating its potential applications in providing solutions for the industry.

Keywords: Task planning, shoe manufacturing logistics, SPECTER.

1 Introduction

Solving and automating complex manufacturing logistics tasks in order to produce a variety of products, has been one of the areas of research interest in the field of robotics and in particular their applications to manufacturing logistics. Shoe making is such a labour intensive process that requires many different sizes, styles and materials for shoes. The shoe manufacturing workflow undergoes various and complex steps before a quality product arrives at a customer, making it hard to automate the planning of such a production. Among the major challenges affecting shoe manufacturing are inefficient utilization of resources, including energy, materials and human resources, leading to increase the cost of the final product.

The manufacturing of shoes consists of multiple workflows with intermediate stages until a pair of shoes is produced. Some of the workflows are the shoe designing, cutting from leather to textiles, stitching, final assembly and packing. Each workflow is distinguished in more individual steps. This work focuses on the optimization of the final assembly workflow and its individual steps of a shoe manufacturing industry in order to optimize the intra-factory logistics. The challenge is that a single production line consists of many intermediate steps and multiple types of production processes depending on the customer order.

Utilizing the SPECTER task planning framework proposed by the authors in [1], [2], different scenarios are studied, to determine the resources and the time required for shoes production depending on the available human workers in the factory as well as the sequence of actions that need to be performed (i.e. the machines/robots operation sequence, the materials utilization, worker actions). The presented results depend on the assumptions, the accuracy of the data and on the level of abstraction and should be considered as a preliminary result that demonstrates the capabilities of our modeling framework.

The rest of the paper is organized as follows: Section 2 presents the description of the workflow, and the workflow abstract model, while section 3 presents the results of 3 different scenarios. Section 4 concludes the paper.

2 Analysis and Modeling

2.1 Description of the Final Assembly Workflow

Final assembly is the workflow where upper leather is shaped, lasted and assembled with sole to get final the product i.e. the shoes. The final assembly is performed before the packing procedure. The main techniques of final assembly

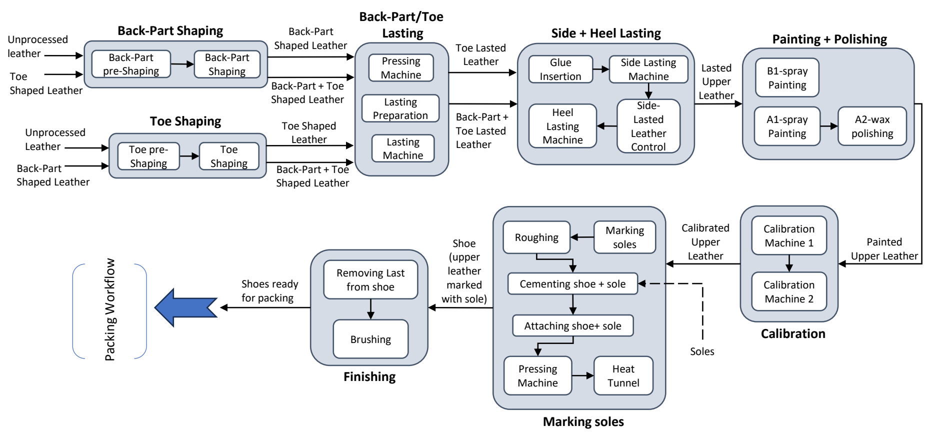

Fig. 1. Diagram of the final assembly workflow.

used in the shoe manufacturing industry, presented in Fig.1 are: **Toe Shaping:** Unprocessed leather or back-part shaped leather is doubled shaped for preserving the shape and the original appearance of the shoe. **Back-Part Shaping:** Unprocessed leather or toe shaped leather is doubled shaped for preserving the shape and the original appearance of the shoe. **Lasting:** The unprocessed leather or back-part shape leather or back-part and toe shaped leather can be processed. In this stage, the upper leather is attached to the bottom of the shoe. **Side and Heel Lasting:** Setting the final shape of the shoe and holds it in place so the outsole can be permanently attached. **Painting and Polishing**, **Calibration:** Calibrating the shoe last. **Marking soles:** Marking the sole in the upper lasting leather, then roughing and cementing shoe with sole. When shoe with sole is attached, the shoe is pressed and then passed through the heat tunnel. **Finishing:** Removing last from shoe's inside, then brushing. Finally, the shoe is produced and continues to packing workflow.

2.2 Abstract Model

In order to model the workflow shown in Fig. 1 an abstraction is required to cast the problem in the discrete processes domain of the SPECTER framework. Due to space restrictions, an outline of the process abstraction is depicted in Fig. 2. The nodes of the diagram represents the processing steps and buffer zones, whereas the arrows indicate the input and the output products of each process and buffer zone.

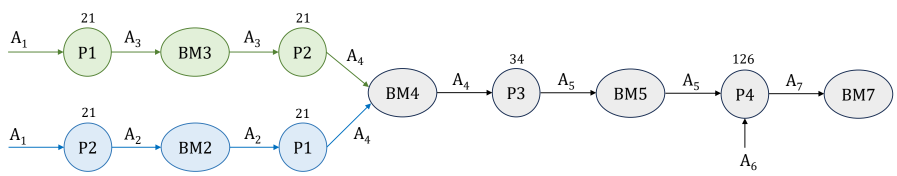

Fig. 2. Workflow abstraction. Numbers above circles indicate duration (sec)

Workers and items are modelled as agents expressed as ϵ_0-NFAs [1,2]. The detailed representations of each agent are beyond the scope of the current paper. More specifically, the unprocessed leather is modeled as A_1; the toe-shaping leather is modeled as A_2; the back-part shaping leather is modeled as A_3; the back-part and toe-shaping leather is modeled as A_4; the lasted leather is modeled as A_5; the soles are modeled as A_6; and the shoes are modeled as A_7. Additionally, 3 workers are considered working in the factory and modeled as A_8, A_9, A_{10} respectively.

Step $P1$ represents the back-part shaping, $P2$ the toe shaping, $P3$ the back-part and toe lasting processes. The processes of side and heel lasting, painting and polishing, calibration, marking with soles and finishing are grouped in step $P4$ since no sequence changes are allowed. Moreover, $BM2$ represents the buffer zone for items modeled as A_2, $BM3$ the buffer for A_3, $BM4$ the buffer for A_4, $BM5$ the buffer for A_5 and $BM7$ the buffer for A_7. The processing steps and the buffer zones are considered as agents locations.

The unprocessed leather A_1 can be converted to the back-part shaping leather A_3 at $P1$ and then, A_3 placed at buffer $BM3$. Also, A_1 can be converted to A_2 at $P2$ and then, A_2 is placed at buffer $BM2$. Item A_4 can be produced at $P1$ using item A_2 or at $P2$ using item A_3. Then, A_4 is placed at $BM4$. Item A_5 is produced at $P3$ using item A_4. Item A_7 is produced at $P4$ using items A_5 and A_6. Finally, item A_7 is placed at $BM7$.

3 Case Study Results

We run 3 scenarios utilizing 1, 2 or 3 workers respectively. We assume that there are unlimited resources of unprocessed leather at $P1$ and $P2$; and soles are at $P4$. For the initial conditions we assume that toe-shaping leather, back-part shaping leather, back-part and toe-shaping leather, lasted leather and shoes have not been produced yet, the workers could be anywhere in the factory.

1st scenario: 1 worker. For the 1st scenario, we considered 8 agents in total; 7 items and 1 worker. The cardinality of the environment's state space is 14,400 states. The objective is to produce A_7 and locate it at $BM7$ utilizing 1 worker.

In the solution computed by SPECTER, the objective is fulfill after 20 steps. In words, (T_1) worker goes at work-cell $P1$, (T_2) worker inserts A_1 in machine at $P1$, (T_3) A_3 is produced at $P1$ after 21 seconds, (T_4) worker places A_3 at $BM3$, (T_5) worker goes at work-cell $P2$, (T_6) worker inserts A_1 in the machine at $P2$, (T_7) A_2 is produced at $P2$ after 21 seconds, (T_8) worker places A_2 at $BM2$, (T_9) worker inserts A_3 in machine at $P2$, (T_{10}) A_4 is produced at $P2$ after 21 seconds, (T_{11}) worker places A_4 at $BM4$, (T_{12}) worker goes at work-cell $P3$, (T_{13}) worker inserts A_4 in machine at $P3$, (T_{14}) A_5 is produced at $P3$ after 34 seconds, (T_{15}) worker places A_5 at $BM5$, (T_{16}) worker goes at work-cell $P4$, (T_{17}) worker inserts A_5 in machine at $P4$, (T_{18}) worker inserts A_6 in machine at $P4$, (T_{19}) A_7 is produced at $P4$ after 126 seconds, (T_{20}) worker places A_7 at $BM7$. Thus, the task is fulfilled; shoes produced and places at buffer zone $BM7$. The time required to implement the solution is 269 seconds utilizing 1 worker for the whole process.

2nd scenario: 2 workers. For the 2nd scenario, we considered 9 agents in total; 7 items and 2 workers. The cardinality of the environment's state space is 72,000 states. The objective is to produce A_7 and locate it at $BM7$ utilizing 2 workers.

In the solution computed by SPECTER, the objective is fulfill after 16 steps. In words, (T_1) worker A_8 goes at work-cell $P2$; worker A_9 goes at work-cell $P1$, (T_2) worker A_8 inserts A_1 in machine at $P2$, while worker A_9 inserts A_1 in machine at $P1$, (T_3) after 21 seconds, A_2 is produced at $P2$ and A_3 is produced at $P1$, (T_4) worker A_9 places A_3 at $BM3$, while worker A_8 places A_2 at $BM2$, (T_5) worker A_8 inserts A_3 in the machine at $P2$, while worker A_9 inserts A_2 in the machine at $P1$, (T_6) 2 entities of A_4 are produced after 21 seconds; 1 entity at $P1$ and 1 entity at $P2$, (T_7) worker A_8 places A_4 entities at $BM4$, (T_8) worker A_8 goes at work-cell $P3$, (T_9) worker A_8 inserts A_4 in machine at $P3$, (T_{10}) A_5 is produced at $P3$ after 34 seconds, (T_{11}) worker A_8 places A_5 at $BM5$, (T_{12}) worker A_8 goes at work-cell $P4$, (T_{13}) worker A_8 inserts A_5 in machine at $P4$, (T_{14}) worker A_8 inserts A_6 in machine at $P4$, (T_{15}) A_7 is produced at $P4$ after 126 seconds, (T_{16}) worker A_8 places A_7 at $BM7$. The time required to implement the solution with concurrent execution capability requires 238 seconds.

3rd scenario: 3 workers. For the 3rd scenario, we considered 10 agents in total; 7 items and 3 workers. The cardinality of the environment's state space is 360,000 states. The objective is to produce A_7 and locate it at $BM7$ utilizing

3 workers. The solution provided by SPECTER consists of 16 steps from (T_1) to (T_{16}) as described in scenario 2 but in this case the solution utilizes worker A_9 instead of A_8 and worker A_{10} instead of A_9. The time required to implement the solution with concurrent execution capability requires 238 seconds.

Fig. 3 demonstrates the results from the 3 case studies.

Fig. 3. Optimal cost (time) for the three case studies

4 Conclusions

In this paper a case study for a manufacturing logistics optimization problem is presented, utilizing the SPECTER task planning framework. An abstraction was proposed that modeled key features of the work flow and the resulting model abstraction was implemented on the SPECTER task planner. Three case studies were investigated, with 1, 2 and 3 workers working on the production line. Interestingly a decrease in the production time was observed only when a second worker was added in the workflow but no change was registered when a third worker was added. The results concluded that an increase above the optimal number of workers will not decrease the production time. Further investigations with different machines/robots/buffers and factory layout arrangements are under consideration as future work.

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