Optimization of assembly lines with collaborative robots

Optimisation de lignes d'assemblage avec des robots collaboratifs

Laboratoire : LS2N

Début : 01/12/2020 (dès que possible)

Financement : IMT Atlantique

Cofinancement : Rennes School of Business

Encadrement :

- Maher Agi, Rennes School of Business, maher.agi@rennes-sb.com
- Alexandre Dolgui, IMT Atlantique, LS2N, alexandre.dolgui@imt-atlantique.fr
- Öncü Hazır, Rennes School of Business, oncu.hazir@rennes-sb.com
- Simon Thevenin, IMT Atlantique, LS2N, simon.thevenin@imt-atlantique.fr

Mots clés en français : Equilibrage de ligne, optimisation combinatoire, cobots, facteurs humains.

Mots clés en anglaise: Assembly line balancing, combinatorial optimization, cobots, human factors.

Context

Industry 4.0 fosters the adoption of collaborative robots (cobots). Indeed, recent advances in artificial intelligence and sensor devices have given rise to new type of robots which are able to collaborate with humans and to perform wider variety of tasks (Olsen & Tomlin, 2020). These developments also led to the emergence of human/robot collaborative (HRC) manufacturing systems, where humans and robots work side by side (Weckenborg et al. 2019). However, these robots are expensive, and their introduction in manufacturing systems requires significant efforts and investments. Therefore, manufacturers must carefully design the HRC system, and they must manage the operations properly. Thus, they need to use optimization models to get the full benefits of the cobots. In this regard, this thesis aims to provide tools and methods to design assembly lines with cobots. Mathematical models that optimize time and cost objectives considering ergonomics and reconfigurability constraints will be developed.

From mathematical and computer modeling perspectives, the robot's characteristics seem similar to those of human operators, and this could explain the scarcity of operations management literature on HRC systems. In other words, both humans and robots are considered as resources with a specific set of skills. However, robots and humans have different characteristics. On the one hand, robots possess high speed, accuracy, tirelessness, and force, but they are quite expensive. On the other hand, human workers are intelligent, creative, flexible, and able to work with different tools in different situations. These differences in characteristics bring various challenges in the designing HRC systems, such as in combining efficiently the human and robot skills, integrating the ergonomics concerns and constraints, and in designing reconfigurable HRC systems where workers and cobots move from a station to another to rebalance the line when needed.

Scientific challenges:

Manual assembly line balancing is an NP-hard problem. The inclusion of possible collaboration with robots makes the problem even harder, since the operation durations will be different if the operation is performed by the worker only or in collaboration with a cobot. Besides, accounting for ergonomics adds another level of difficulty. Finally, the design of a line with the right balance between reconfigurability and costs is a challenging task.

Literature and Research Opportunities:

HRC systems offer an alternative to manual workstations, resulting in workstations gathering the strengths of both humans and robots. Multiple companies already adopted HRC systems. For instance, cobots work around the workforce and take over dangerous tasks in the BMW production plant (Michalos et al., 2018a), and cobots assist workers when needed in the Audi assembly plant (El Makrini et al., 2018). Several studies (e.g., Rahman & Wang, 2018) report the benefits of HRC systems in terms of throughput, product quality, ergonomics, safety, and flexibility. Typically, manufacturers introduce cobots in their production system to improve the level of safety, ergonomics, quality, flexibility, and reconfigurability (Krüger et al., 2011).

There is a growing amount of research related to task scheduling in HRC systems. Typically, these works focus on the assignment of tasks to cobot and workers (e.g., Rahman & Wang, 2018). However, to the best of our knowledge, (Weckenborg et al., 2019) and Weckenborg and Spengler, 2019 are the only works that optimize assembly lines with cobots. The first study presents a mathematical model that minimizes the cycle time and uses genetic algorithm to solve the problem. On the other hand, the second study presents a mathematical model that integrates costs of ergonomic design and solves the problem directly using CPLEX.

These models can be extended by integrating various other optimization criteria, ergonomics constraints, and flexibility for line reconfiguration. There is also a need for developing effective and efficient problem specific solution approaches and extension of their computational test instances.

Larger instances need to be solved to integrate the complexity or real life cases. Through these extensions, real life problems could be better represented and properly addressed.

Despite the lack of literature on assembly lines with cobots, our work can take advantage of the abundant literature on assembly line balancing, and various research streams can be investigated to account for the specificities of HRC systems. For instance, in dual resource-constrained (DRC) systems literature (Xu et al., 2011), workers operate a machine to perform a task. In two-sided assembly line balancing (Make et al.2017), two workers cooperate in the same station. Finally, in a multi-manned assembly line, multiple workers can collaborate to perform a task (Dolgui et al., 2018).

Objectives

The thesis aims to provide models and methods to manage assembly line balancing with cobots. More precisely, we have the three following goals:

(1) To extend the assembly line balancing literature to account for different cobot interaction modes. This extension includes the definition of manual, automated, and hybrid tasks. Humans perform manual tasks, cobots perform automated tasks, and hybrid tasks require both human and cobot at the same time. These different task types create complex precedence constraints. The inclusion of HRC features into a DRC scheduling problem would lead to the creation of hybrid workstations with the required skill sets. As exposed in (Hashemi-Petroodi et al. 2020), HRC systems are composed of stations with a wide range of skills, and the design of the right station requires the use of advanced optimization approaches. These approaches can be designed based on the literature on dual resource constraints, two-sided assembly line, or multi-manned assembly line.

(2) To extend the model to account for ergonomic constraints. Workforce ergonomics is the main concern in the design of an HRC system (Botti et al., 2017). Usually, manufacturers seek to assign painful or dangerous tasks (e.g., tasks requiring twisting or lateral forces) to robots (Argote et al., 1983; Akella et al., 1999). There is considerable literature on ergonomics for HRC systems, but researchers have mostly focused on the cobot technological aspect. However, a careful assignment of tasks to workstations can improve the ergonomics in such systems (Weckenborg and Spengler, 2019). Ergonomics can be accounted for by minimizing the total energy expenditure of workers (Jaber & Neumann 2010; Sammarco et al. 2014; Botti et al. 2017).

(3) To study the reconfigurability issues of HRC systems. The cobots are fast to setup, easy to program, and mobile. These characteristics give them an advantage in flexible assembly lines as they can easily be re-deployed among stations. HRC systems are usually characterized by a high level of flexibility and reconfigurability. However, it comes at a cost. The design of HRC systems with the right level of flexibility requires advanced optimization methods. Such methods can leverage on the assembly line balancing literature and may include stochastic or robust optimization techniques to account for different product sequences, changes in customer demands, and other uncertainties (Hazir and Dolgui 2013, Hashemi-Petroodi et al. 2020b).

Industrial Transfer

As mention earlier, the industry is starting to integrate cobots in the assembly lines. Several of our contacts (PSA) have interest in the using cobots. This project is positioned as an academic research in relation to the needs expressed by industrial.

To give an example, PSA Groups expressed the difficulty in managing production lines with both automated operation (for classical operations), and manual operation (for new items such as hybrid engines where automation is not available). To overcome these difficulties, PSA will develop fenceless environments where robots can adjust their behavior and collaborate with human operators. Therefore, safe tools are required for *safe reconfiguration in fenceless environment*.

Required skills

- Connaissance en programmation mathématique, optimisation, méta-heuristiques.
- Bonnes compétences en programmation (Python, C++).
- Anglais : lu, parlé, écrit

References

Argote, L., Goodman, P. S., & Schkade, D. (1983). The Human Side of Robotics: How Worker's React to a Robot. Sloan Management Review.

Akella, P., Peshkin, M., Colgate, E. D., Wannasuphoprasit, W., Nagesh, N., Wells, J., ... & Peacock, B. (1999). Cobots for the automobile assembly line. In Proceedings 1999 IEEE International Conference on Robotics and Automation (Cat. No. 99CH36288C) (Vol. 1, pp. 728-733). IEEE.

Botti, L., Mora, C., & Regattieri, A. (2017). Integrating ergonomics and lean manufacturing principles in a hybrid assembly line. Computers & Industrial Engineering, 111, 481–491.

Dolgui, A., Kovalev, S., Kovalyov, M. Y., Malyutin, S., & Soukhal, A. (2018). Optimal workforce assignment to operations of a paced assembly line. European Journal of Operational Research, 264(1), 200-211.

El Makrini, I., Elprama, S. A., Van den Bergh, J., Vanderborght, B., Knevels, A. J., Jewell, C. I., ... & Berte, J. (2018). Working with walt: How a cobot was developed and inserted on an auto assembly line. IEEE Robotics & Automation Magazine, 25(2), 51-58

Elprama, B. V. S. A.f, El Makrini, I., & Jacobs, A. (2016). Acceptance of collaborative robots by factory workers: a pilot study on the importance of social cues of anthropomorphic robots. In International Symposium on Robot and Human Interactive Communication.

Hashemi-Petroodi S. E., **Thevenin S.**, Kovalev S., **Dolgui A**. (2020) A survey on operations management methods for hybrid human-robot collaborative systems in manufacturing, submitted

Hashemi-Petroodi S.E., **Dolgui A**., Kovalev S., Kovalyov M.Y., **Thevenin S**. (2020b). A survey on workforce planning in manufacturing systems, submitted.

Hazır Ö., **Dolgui, A.** (2013). Assembly line balancing under uncertainty: Robust optimization models and exact solution method. Computers & Industrial Engineering, 65(2), 261-267.

Jaber, M. Y., & Neumann, W. P. (2010). Modelling worker fatigue and recovery in dual-resource constrained systems. Computers & Industrial Engineering, 59(1), 75-84.

Krüger, J., Schreck, G., & Surdilovic, D. (2011). Dual arm robot for flexible and cooperative assembly. CIRP annals, 60(1), 5-8.

Make, M. R. A., Rashid, M. F. F. A., & Razali, M. M. (2017). A review of two-sided assembly line balancing problem. The International Journal of Advanced Manufacturing Technology, 89(5-8), 1743-1763.

Michalos, G., Kousi, N., Karagiannis, P., Gkournelos, C., Dimoulas, K., Koukas, S., ... & Makris, S. (2018a). Seamless human robot collaborative assembly–An automotive case study. Mechatronics, 55, 194-211.

Olsen, T. L., & Tomlin, B. (2020). Industry 4.0: Opportunities and Challenges for Operations Management. Manufacturing & Service Operations Management, 22(1), 113-122.

Rahman, S. M., & Wang, Y. (2018). Mutual trust-based subtask allocation for human–robot collaboration in flexible lightweight assembly in manufacturing. Mechatronics, 54, 94-109.

Sammarco, M., Fruggiero, F., Neumann, W. P., & Lambiase, A. (2014). Agent-based modelling of movement rules in DRC systems for volume flexibility: human factors and technical performance. International Journal of Production Research, 52(3), 633-650.

Weckenborg, C., Kieckhäfer, K., Müller, C., Grunewald, M., Spengler, T. S. (2019). Balancing of assembly lines with collaborative robots. Business Research, 1-40.

Weckenborg, C., Spengler, T. S. (2019). Assembly Line Balancing with Collaborative Robots under consideration of Ergonomics: a cost-oriented approach. IFAC-PapersOnLine, 52(13), 1860-1865.