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Overhead shuttle design for a flat panel display production line considering the contactless power supply capacity

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ABSTRACT

The overhead shuttle (OHS) is a widely used automated material handling system (AMHS) for flat panel display (FPD) manufacturing lines. Recently, an OHS using wireless power transfer (WPT) technology, which transfers power remotely from the contactless power supply (CPS) installed in the track, has been widely applied. The OHS with WPT technology is revolutionary because it removes the need for a battery, as the power is continuously transferred while the OHS is in motion. Unlike a conventional battery-powered OHS, the WPT-based OHS does not need to travel to charging stations to recharge the battery, and therefore, delivery efficiency is increased. One of the key design problems in developing a WPT-based OHS system is determining the power distribution in the track. Typically, the track is divided into multiple zones, and the power supply for each zone is determined independently. This decision is critical because it determines the maximum number of OHSs that can be in a zone at the same time. In this paper, we introduce an optimization algorithm to logically determine the power supply in each zone. The critical problem is that the power supply affects the OHS delivery capacity and the total installation cost. We propose an efficient solution algorithm using the monotonicity and primal-dual properties of the optimization model. Two heuristics algorithms are proposed—gradient-search and genetic-algorithm-based approaches. The numerical case from an actual system is investigated to cross-validate the proposed algorithms.

1. Introduction

Automation has become a critical factor in flat panel display (FPD) manufacturing. Liquid crystal display (LCD) manufacturing, which is the major FPD industry, requires a fully automated production system due to the large panel size and delicate nature of thin glass panels (Jang, Choi, & Kim, 2005). Almost all of the LCD production processes are carried out using an automated material handling system (AMHS). OLED panel manufacturing, which is the second largest industry for FPD, also requires a fully functional AMHS.

On FPD production lines, including those for LCD and OLED manufacturing, thin glass is the base substrate. Multiple electrical/chemical layers are created through repetitive processes in processing machines called *equipments* or *tools*. The glass panels are then moved from one equipment to another. For transportation, they are stored in a *lot* called a *cassette*, which contains 10–50 panels. The cassette or lot is the basic unit of transport between equipments through the AMHS. (Hereafter, we use the terms "cassette" and "lot" interchangeably.).

A typical FPD line layout is the bay type, with each bay containing a central corridor. Equipments face each other across this central corridor. There are two main types of AMHS delivering cassettes in the corridors between equipments. One is a crane type AMHS called a stocker system, which is a large crane similar to the AS/RS system in a warehouse moving on the rail installed in the corridor. The other is an overhead shuttle (OHS) system, as shown in Fig. 1, in which unidirectional shuttles move on a rail installed in the corridor. In this paper, *OHS system* refers to the OHS shuttles/vehicle units, tracks, and loading and unloading ports, and *shuttle* refers to the vehicle unit in the system. For a better understanding of the OHS system, the readers are advised to watch the video clip created by the authors, which can be accessed from the link: https://youtu.be/csPPkDRpXYA.

An early version of the OHS system uses battery power: battery-equipped shuttles deliver the lots, and battery recharging is done at a charging station. For this system, the shuttles need to travel to charging stations when the energy level in the battery is low. Another version is a system using conductive power transfer, whereby the required power is supplied through a brush or conductive wheels. This solution eliminates the use of the battery, but there is a risk of the brush or conductive

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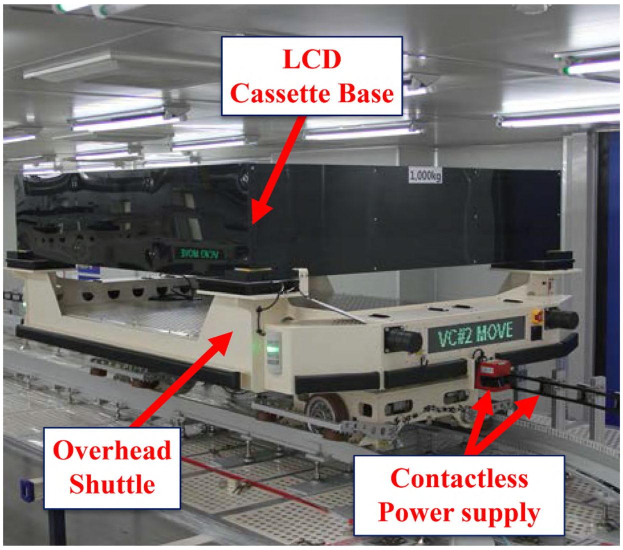

Fig. 1. Overhead shuttle powered by contactless power supply.

wheels creating particles generated by contact friction. The most advanced version is an OHS system using *wireless power transfer* (WPT) technology. In this system, power supply units in a *contactless power supply* (CPS) installed along the rail transfer power wirelessly to the shuttles as shown in Fig. 1. The technology is innovative in that the charge is carried out while the shuttles are in motion. The main advantages of the WPT-based OHS system are that it does not need any extra travel to charge the battery and does not generate particles from friction. The WPT-based OHS thus eliminates the disadvantages of the battery-powered and conductive-based OHS systems. Fig. 2 illustrates the OHS system using the CPS.

However, the WPT-based OHS (hereafter, "OHS" refers to the WPT-based OHS) has an additional design issue that is not a feature of the previous systems: the power supply capacity. The track is typically divided into multiple zones, as shown in Fig. 3, and the power is delivered in different amounts to each zone. The power amount is determined by the power capacity of the CPS in each zone. The installation cost increases as the power of the CPS units increases. The CPS power allocation in each zone is critical in the OHS operation because the power determines the maximum number of shuttles that can be in a zone at the same time.

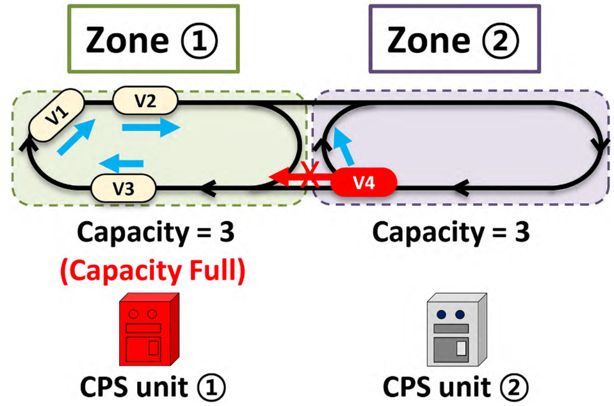

Fig. 3. Example of temporal blocking due to CPS capacity limitation.

This problem is not trivial. If the CPS power is high for all zones, many shuttles can travel to different zones without much restriction. However, the installation cost of the track will increase, which may lead to a wasted investment. If the CPS power is not sufficient, then shuttle movement from one zone to the other is frequently restricted. There is a risk of inefficient traveling, or it may be impossible to meet delivery requirements. For example as, shown in Fig. 3, suppose the OHS tracks are divided into two different zones. The CPS capacity of each zone is three shuttles. That is, no more than three shuttles can be at each zone. A shuttle, V4, in the figure, has just picked a lot at Zone 2 and is about to enter Zone 1 to deliver it. At this moment, Zone 1 already has the maximum number of shuttles. The shuttle is unable to enter Zone 1, and instead it will circulate around Zone 2 until the number of shuttles in Zone 1 falls below the maximum. This is called *blocking*. If the delivery demand is high, blocking may occur frequently and cause a delivery delay.

The contribution of the work is clear. Note that the problem is motivated by industry need. Determining the power capacity of CPS has been a continuing issue in industry. If inadequate power is provided in CPS, it causes unnecessary OHS delay due to blockage. However, the provision of too much capacity can result in over-investment in CPS systems. The industry has agreed that there should be a more systematic way of designing the WPT-OHS that considers the CPS power capacity. Although this problem has been present in the industry for a long time, it has not been addressed in the academic community. The modeling and approach presented in this paper are the first step to formalizing

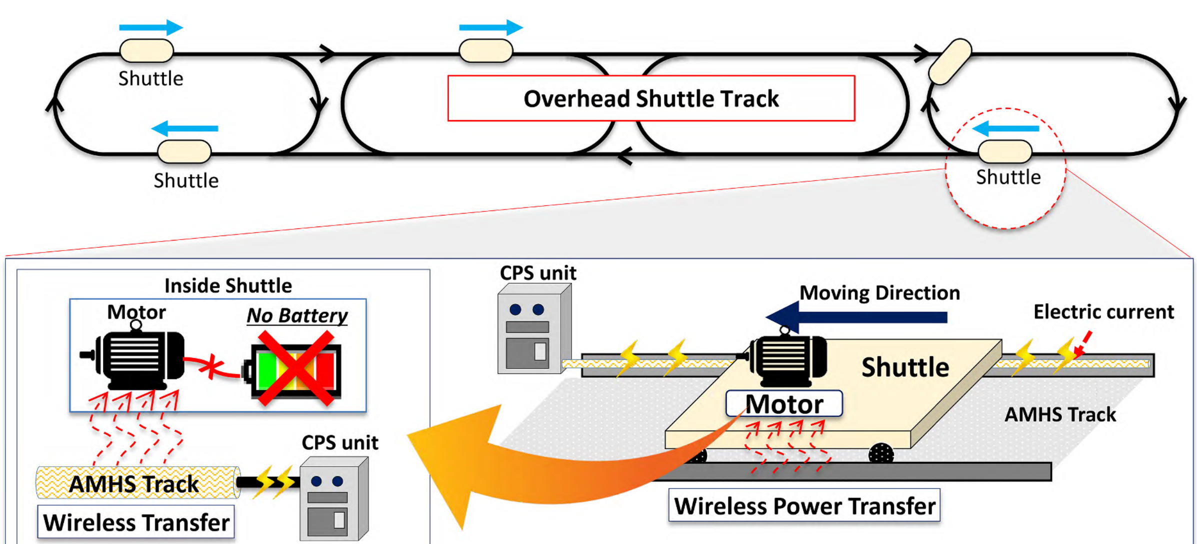

Fig. 2. The configuration of the WPT based OHS system.