Journal of Manufacturing Processes
Vol. 5/No. 1
2003

Colored Petri Net Modeling of Metal Distribution in a Job Shop Iron Foundry: Improving Flow in a Pull System with Perishable In-Process Inventory

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Abstract

Colored Petri nets with time are used to model the dynamic behavior of a foundry job shop to address the basic issue of matching molten iron production capability with casting demands. The objective is to achieve the maximum iron throughput per day for the chosen configuration. The fundamental pulling forces in the system are analyzed and then combined to provide a picture of the overall pulling behavior on the demand side of the system. A necessary condition to avoid deadlock is developed and used to develop the best demand pattern. This pattern of demand is then compared to the supply capability of the furnaces. The fundamental parameters of the system are identified and analyzed and a sufficient condition for deadlock avoidance is developed. The conditions leading to finding the best compromise values for the decision variables are investigated.

Keywords: *Foundry Job Shop, Metal Distribution, Deadlocks, Optimum Throughput, Petri Nets*

Introduction

The flow of material (molten metal) from stage to stage in the job shop foundry system is accomplished in discrete chunks of differing sizes. Greater efficiency occurs when the flow can be accomplished with fewer exchanges. In a job shop situation like the one studied, the desired mix of products is specified and this creates a constraint that must also be satisfied. The situation could be viewed as similar to the kanban operation (Becker and Szczerbicka 1998) except that the in-process material is perishable. Coordination of the molten metal distribution to maximize throughput while being bounded by the maximum rate of the fundamental pulling force of mold creation is investigated.

What exactly is a pull system? For the purposes here, a pull system is one in which the motivating force for all flows in the system is not located at the beginning or front of the system. Rather, it is somewhere inside or at the output; the conclusion of the process. This definition would allow a bottleneck in a system to be viewed as the pulling mechanism. The pulling element simply provides the leadership that the rest of the elements must adjust to in order to achieve the best flow. The characteristics or properties of these adjustments are of primary interest to the system designer. Orders for castings are the reason for creating molds, which are the basic pulling force in the foundry system.

Colored Petri nets (CPNs) with time (Davis and Alla 1992; Jensen 1994) offer a straightforward avenue and some significant advantages for modeling pull systems with concurrent activities. The power of the picture is significant, but just as important is the ability to analyze the coordination of concurrent action that can be ‘driven’ (demanded) from anywhere in the process. Usually, these foundry systems are analyzed through calculations about the individual elements, and experience, or through the use of simulation (Prisk et al. 1997). Samples of animated foundry simulations can be found on the Web as well.

Informally, a CPN is a graph with two types of nodes: *places* and *transitions*. Place nodes can represent physical or functional locations in a process. Transition nodes represent activities in a process. Entities that move through the network are called *tokens*. Place nodes accumulate tokens, and transition nodes operate on tokens. The nodes are connected with *weighted arcs* that always point from one node type to the other node type. The tokens are moved within the net from one node type to another according to the arc weights and “firing” rules. For the foundry, tokens might represent molds and molten iron in a ladle, and the “firing” rule might be ‘move 500 iron tokens to pouring deck 1 as soon as there are 5 mold tokens available.’ An assignment of tokens to each place in the network is called a *marking* (Davis and Alla 1992). The convention of associating time with transitions is followed here.

The objectives of this study were as follows:

1. Verify that the capacity of the electric furnaces chosen is sufficient to support the desired daily throughput of iron castings desired by foundry management.
2. Investigate the effect of ladle sizes on the overall flow of iron per day.

For objective (1), a simulation was also carried out, and the results agreed with the CPN analysis. The two methods were equal in the amount of effort required to get answers. For objective (2), the simulation approach did not offer the same advantages. The CPN approach made it much easier to visualize the process in action and gain insight from discussion with the foundry experts. Additionally, building an animated simulation output would be much more work. Finally, it is not clear that the same properties could have been discovered.

Iron Foundry Job Shop

The production facility consists of a furnace (or furnaces), pouring decks, and some kind of transportation mechanism (railcar) for moving the molten iron from the furnace to the decks. A schematic representation is shown in *Figure 1*. The operation can be envisioned as follows. Molten iron is poured into the crucible of the railcar. The railcar moves to the pouring decks and waits for a signal that a deck is ready to receive iron. The railcar moves to the deck and fills the deck ladle. Then the deck begins pouring while the railcar awaits the next signal from another deck. When the railcar is empty, it returns to the furnace to refill and the cycle starts again. There are also some constraints, for example, the length of time the iron will remain in the proper heat range after it has been withdrawn from the furnace and from the railcar. There may also be other rules imposed by management (for example, product mix). The objective is to produce all the castings scheduled for all the decks in the shortest possible time, with as little wasted iron as possible. Throwing away iron is called ‘pigging’ and occurs commonly. The iron that is pigged is recycled but is lost as throughput for the period.

Orders for castings translate into a schedule of specific activities to be carried out on an assigned pouring deck (a moldmaking machine, a mold conveyor, and a ladle for pouring iron). The activities will require a pattern, sand, work instructions, molten iron of the proper temperature, and perhaps a supply of ‘cores.’ The pattern makes the desired impression in the sand mold and the core is added to complete the definition of the shape of the casting. Molten iron is poured into a specified hole in the mold and the casting is formed. After the iron has cooled, it is separated from the mold and the sand can be recycled. The casting is then processed further to its desired form. Only the pouring portion of the operation is modeled here because this is where the pulling force in the system manifests itself.

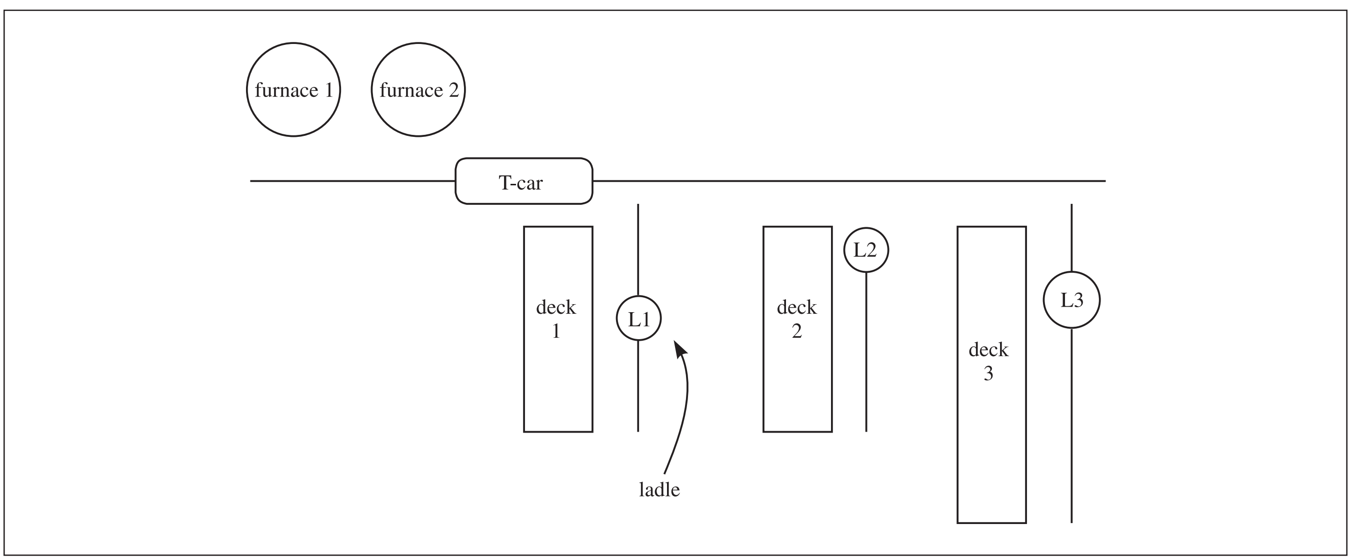

Figure 1
Schematic of Pouring Layout

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