THE FLOW JUNCTION MODEL AS A FUNDAMENTAL ELEMENT OF CYBER-COLLABORATIVE FUTURE WORK SYSTEMS AND NETWORKS: A RESEARCH OVERVIEW

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PRISM Center
Production, Robotics, and Integration Software for Mfg. & Management

"Knowledge through information; Wisdom through collaboration"

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A. Abstract

The purpose of this article is to study and overview a fundamental workflow logic element for cyber collaborative future work and factories (C2F) as it recurs in the design of most systems and networks, and as part of our NSF Grant 1839971: *Collaborative Research: Pre-Skilling Workers, Understanding Labor Force Implications and Designing Future Factory Human-Robot Workflows Using Physical Simulation Platform.*

B. The Flow Junction as a fundamental model of manufacturing, production, logistics, and service workflow logic

Consumers are increasingly demanding from suppliers:

1. A wider and scalable range of products,
2. per cost, quality, reliability, and service agreements,
3. with quicker and more accurate delivery capabilities.

In response, many manufacturing, production, and service designers often employ as part of their material flow process "flow junctions," or "flow control stations." The following definition focuses on physical material flow, as it has evolved throughout the history of human civilization. The astute modern reader, however, can immediately distinguish that flow in flow junction implies movements beyond just physical material, e.g., signals, data, information, knowledge, intelligence, etc. (as will be discussed below too.)

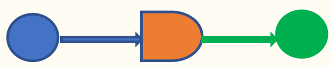
Flow Junction definition**:** In a Flow Junction, different parts or components arrive from multiple sources and are grouped and sorted based on common attributes: type of product, storage requirements, priority of order, destination in process, shipping or distribution plan, etc. Hence, flow junctions generally include sorting and merging functions.

The goal of utilizing a Flow Junction is to improve flexibility and cost/time/quality/reliability/serviceability measures. Examples of such junctions, including sorting and merging stations, can be found in:

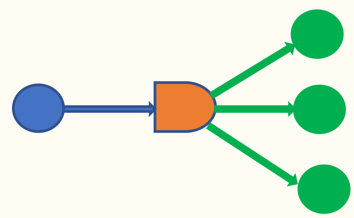
- Transportation (e.g., airports [1], shipping and distribution hubs, cross docking depots);
- Food and beverage industry [2];

- Manufacturing and logistics [3];
- Construction parts and materials;
- Automated storage and retrieval systems;
- Healthcare and medical supply chains;
- Test, maintenance and repair; and more.

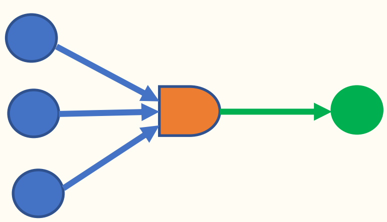
The general flow logic of a Flow Junction is shown in Figure 1.



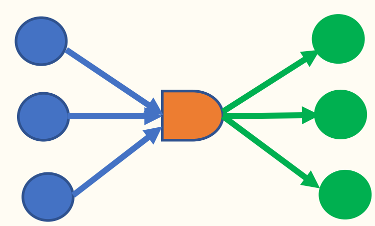
a. *1 to 1 flow*, e.g., tool magazine kitted at tool - room and moved to machining-center.



b. *1 to many flow*, e.g., one supplier distributes to multiple job-shops.



c. *Many to 1 flow*, e.g., several wire-cutters move various wire-sets as kits to a single assembly line.



d. *Many to many flow*, e.g., cross-docking from suppliers to clients.

Figure 1. Four typical flows in Flow Junctions. Flow Junction -- Source -- Destination --

C. Flow Junction Illustration: The Kirby Risk Service-Center (KRS) Case Study

To illustrate a typical workflow design with flow junctions [4, 5, 6], consider the modeling, improvement and optimization of kitting stations for the electrical harness industry, with KRS Case Study, as an example [7].

Parts kitting (Figure 2) is a frequently used method to deliver pre-organized and often pre-inspected parts to assembly lines/workstations. Kitting policies usually involve: 1) grouping all parts required to assemble one complete unit of end-product or sub-assembly; and 2) placing these grouped parts into one or more containers.

The main advantages of kitting: Material flow downstream is simplified, errors are prevented or eliminated early; inventories, space requirements and holding costs are reduced. These advantages, however, come at the additional expense of supporting the additional workforce and automation required to perform the kitting operations, and additional costs involved with errors induced from this additional workforce [6].

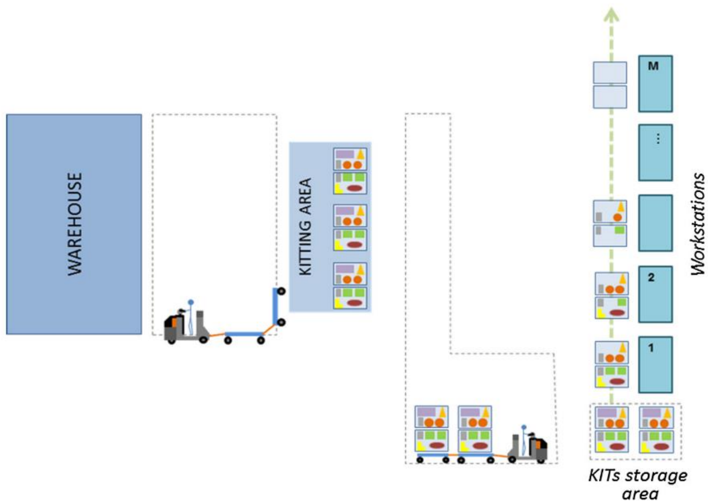


Figure 2: Kitting system scheme (source: [6]) as part of a flow junction model

While the scheme in Figure 2 illustrates the kitting function well, it does not specify the in-flow into the warehouse, while the out-flow is shown with *M* workstation destinations, and unspecified external destination(s). The KRS flow junction case (see Figure 3) is similar to the general scheme shown in Figure 2 in its kitting function, and its current design can be fully specified as follows: It is a type *d Many-to-Many* flow junction (Figure 1), with:

(1) **In-flow** originating from multiple, *S*, workstations of wire-cutting, testing, and bundling, producing wire-bundles, each marked and identified.

(2) A **flow junction** with in-process storage; kitting, where wire-bundles are first identified, counted, and combined into kits, k_i, i=1, 2…K kit types; each kit container (or tray) is marked and designated for a given work-order. The in-process kits, when completed with all the required kit components, are stored in specific outgoing storage bins.

(3) Once ready, each completed kit is picked-up and delivered to one of several, *W*, workstations, to be assembled into wire harnesses, or directly into sub-assembly products. Usually, several kits are loaded on a cart for transfer.

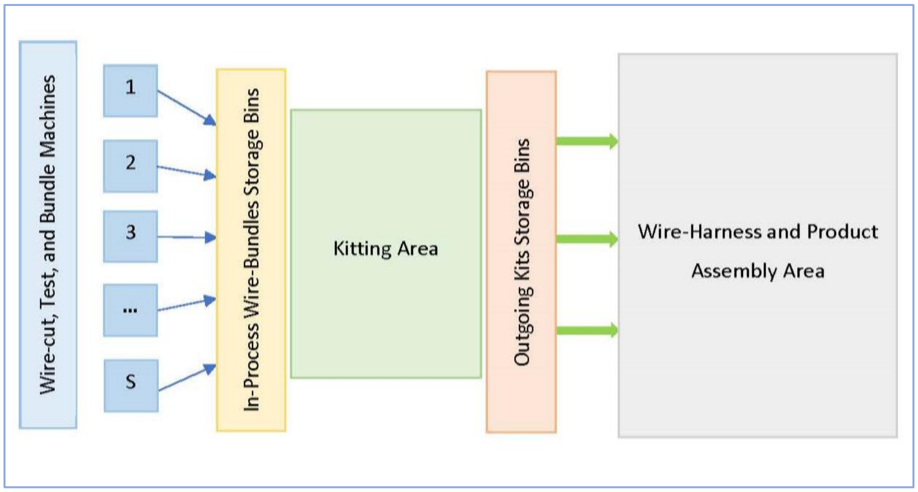


Figure 3. The KRS Case Flow Junction with *S* in-flow source stations, *K* kit types, and *W* destination stations.

D. Kitting tasks, taxonomy and future work advances

Tasks involved in the kitting stations need to be performed in a procedural, pre-determined and logical manner [8], to ensure the process and the involved tasks are simple and can be performed quickly. Small to medium enterprises depend on manual labor for kitting operations, and given the repetitiveness of these tasks, human error can be a prominent cause of errors and conflicts in material handling [9]. Any error arising from the kitting station can be a potential conflict for further steps downstream; additional correction costs, economic losses can be incurred in it is necessary to either correct the steps within the scope of the kitting policy or reduce the overall probability of these errors from arising [9]. Human operators perform a series of physical (picking, placing, traversing, storing, and scanning) and cognitive (decision-making, part-checking, and scan verification) – thus it becomes imperative to create a taxonomy that can address the following requirements:

1. Determine different types of errors that can arise and their classification (cognitive, physical, prior error, etc.);
2. Map these errors to different logical steps of the kitting workflow based activities;
3. Quantify the cost impact of these errors taking into consideration probability of these errors being detected, and cascading impact downstream.

The taxonomy should enable material planners to identify the current gaps (of skill, operation, workflow) and initiate corrective measures to reduce the occurrence of errors and conflicts [9, 10]. Some examples of corrective measures include:

1. **Streamlined and simplified operations:** By standardizing the involved process and ensuring minimal levels of specialization, human-induced errors can be minimized by reducing the cognitive load [11].

2. **IoT/RFID based solutions:** IoT/IoS based design has been shown to provide preventive maintenance of industrial systems in real-time [12]–[14]. While SMEs often rely on barcodes and hand-held scanners for material handling, the usage of RFID has gathered momentum within various

supply chains [13], [15], [16]. We propose an IoT based kitting system that can reduce errors which originate due to cognitive actions (e.g., decisions such as acknowledging when the kit tray is complete and should be sent to temporary storage, when a part is placed in the wrong tray, or vice versa).

3. **Advanced AR/MR dynamic and responsive training of human operators:** Adaptive intelligent tutoring systems [17]–[19] can be used to improve cognitive knowledge and skill sharing, retention, error and conflict reduction, improve and minimize costs and delays for cognitive and physical task training. We can envision the use of (Adaptutor) to improve the task performance for physical tasks (and later, also cognitive tasks) within the kitting workflow, since they also involve local, body-coordinated and spatial tasks as well.

4. **HUB-CI for workflow optimization and harmonization:** To evaluate the usefulness of these improvements, we consider the development of a discrete-event simulator based on HUB-CI [20], [21] logic and services. This simulator takes a modular approach to integrate these improvements, and different levels of collaboration can be evaluated to determine the optimal operating parameters for such a system. HUB-CI is required to ensure that the proposed improvements are integrated into the workflow in a harmonized manner. The following levels are proposed:

    a. **Level 0:** Control (normal workflow)
    b. **HUB-CI Level 1:** Control +
        i. **IoT based improvements**
        ii. **AR training of operators**
    c. **HUB-CI Level 2:** Control + IoT + AR training (and later, wearable AR/MR)

We capture relevant simulated performance metrics such as operator error rate, average operation cost, time, and penalty costs to validate the different levels of HUB-CI. HUB-CI simulator is envisioned as part of our planned PRSP.

5. Preliminary progress in the above directions

Preliminary progress has been accomplished in the four areas outlined above, under this NSF project. They are detailed in the references [22, 23, 24, 25].

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