APPLYING HUMAN-MACHINE INTERACTION DESIGN PRINCIPLES TO RETROFIT EXISTING AUTOMATED FREIGHT PLANNING SYSTEMS

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I. Summary

This master's thesis focuses on the application of human-machine interaction (HMI) design to an existing freight planning system used in a closed loop supply chain business. The system is analyzed along with opportunities for improvement. HMI principles are applied to model, retrofit, and improve the overall joint cognitive planning system consisting of a several-part automated system and human actors.

II. Company Overview

The multi-billion dollar umbrella corporation ("Parent Corporation") of the Company is an international logistics company and closed loop supply chain ("CLSC") ("Parent Corporation 2018 Annual Report"). The Parent Corporation provides a "pool of reusable pallets, crates, and containers," which it aggregates and delivers for use by international leading companies ("Parent Corporation 2018 Annual Report", p.3). The Parent Corporation consists of various components defined by equipment type, including containers and pallets. "[The Parent Corporation's] platforms form the invisible backbone of global supply chains, primarily serving the fast-moving consumer goods, fresh produce, beverage, retail and general manufacturing" ("Parent Corporation 2018 Annual Report", p.3). Operating in over 60 countries, the Parent Corporation oversees hundreds of millions of assets and facilitates over 10,000 daily loads across nearly 500 service centers, hundreds of total pallet management locations (reduced capability service centers), and over half a million collection points ("Company MIT Presentation," 2018). The primary assets for use are the 48" x 40" pallets, fluid containers, and reusable plastic containers ("Company MIT Presentation," 2018, p. 3).

The business model consists of a three-part iterative process:

(1) Parent Corporation issues containers, pallets, and crates to manufacturers;

(2) Customers load equipment with goods and shuttle through the supply chain to end users;

(3) Parent Corporation collects, inspects, and (as needed) rehabilitates equipment for future use.

Currently, manual planning of pallet movements consumes the efforts of 35 logistics coordinators and concerns approximately 45% total load volume (580,000 pallet loads annually in the United States) ("Company MIT Presentation," 2018). The loads planned include issuances, collections, and relocations of pallets ("Company MIT Presentation," 2018). Moreover, due to the load volume and need to move these loads immediately, logistics coordinators and senior logistics analysts (more experienced coordinators) (collectively, as "coordinators") are unable to improve the system by acting strategically. Rather, they spend their entire effort responding to short-fused problems. A consequence of dedicating logistics coordinators nearly exclusively to fire-fighting is the risk they will lose a strategic level appreciation of the overall planning system.

III. Research Question and Hypothesis

Improving the percentage of loads planned through the automated planning process is critical to ensure identified optimality considerations are pursued, reduce costs, and to permit logistics coordinators to prioritize system awareness and improvement over short-term problem solving. In measuring the overall load planning system (automated and manual), key considerations included time spent planning and assigning loads; costs of planning, assignment, and transportation; and service fulfillment measurements (timely and correctly meeting customer equipment requests) ("Company MIT Presentation," 2018).

The research question then becomes: **What process augmentation will incrementally decrease costs, reduce manual load planning, permit a system retrofit (rather than rebuild), and improve the joint (manual and automated) cognitive system iteratively?**

The hypothesis is that human-machine interaction ("HMI") principles, currently used to optimize tightly coupled systems including jet airplanes and air traffic control systems, can be applied to optimize the Company's joint cognitive load planning system. This application is novel both in its use with a freight planning system and so far as it serves to retrofit an existing planning system (rather than serve as a complete system rebuild paradigm). The specific thesis objectives incorporate both conceptual and application goals, including to (1) characterize the current planning system under the HMI joint cognitive system framework, and (2) propose a solution that improves the system from cost (of the loads) and efficiency (manual interventions and focus) perspectives. Accordingly, this project serves to (1) characterize the current system and (2) propose a retrofit solution that iteratively improves the existing system, using HMI frameworks, whose application is novel.

IV. HMI Background

While this project addresses neither the development of the underlying load planning system nor the integration steps for automation, which involve substantial complexity across organizational silos (Ebner, 2015), a broad systems-based approach will be implemented. A systems approach is necessary to identify system parameters, stakeholders, reasons for manual drops from the automated system, and opportunities to work within the current structure to reduce manual interventions. Further, in moving towards more automation, a critical consideration remains the nurturing and maintenance of essential skills by logistics coordinators; stated differently, automation can cause the lapsing of critical employee skills, which are necessary for oversight of the service delivery (Albrecht, 2013). A human-machine collaborative model is ideal both from efficiency and systems development perspectives (Albrecht, 2013). Further, research validates improved outcomes by incorporating human action into the automated planning cycle (Kim, Banks, & Shah, 2017).

Automation is best considered an iterative process, wherein the technical and human systems interact repeatedly to smooth processes and improve workflow (Albrecht, 2013). This is particularly true for the Company, which experiences uncertain and opaque micro-level (location and time) demand from customers and changing systems based on client relationships and freight flows. From a design standpoint, the HMI system should limit complexity and ambiguity to the extent possible (Albrecht, 2013). The modeling of human-machine planning systems is not novel (Ryan, 2011), but has been focused on tightly coupled systems requiring constant user-machine interaction. A critical hurdle is developing standards for the interaction between the automated process and the human exception management efforts (Ryan, 2011). Moreover, identifying the appropriate level of abstraction for the interaction is another key modeling step (Kim et al., 2017).

The modeling of human-machine systems has typically been limited to tightly coupled systems, including nuclear plants and air traffic control (van Wezel, Cegarra, & Hoc, 2010); (Idris, 1994), flight control systems and driver assistance systems (Badreddin & Wagner, 2011), as well as space mission planning and scheduling and military applications (Gaudreault et al., 2017) such as unmanned vehicles (UVs) (Clare, 2010).

However, there is a need for understanding and effectively synchronizing both human and machine actors in other planning systems (van Wezel, Cegarra, & Hoc, 2010). Presently, the Company's opportunity involves the effective use of logistics coordinators, the reduction of manually planned freight movements, and the development of an integrated system that maximizes the skills of both the human actors and the computer freight planning system.

V. HMI Paradigms Applied

Here, the proposed joint cognitive system augmentation applies five HMI design paradigms, namely scenario development, recursive nested behavior-based control structure, task batching, the use of logistics coordinators as soft-data sensors, and the application of displaced transparency through pre-briefing and post-mission debriefing practices. Each instance represents a novel application to a distributed human-machine planning model, particularly in the freight transportation space. Further, the proposed innovation applies broadly to a process augmentation (rather the complete redesign), which is likely to be preferable for many companies to a complete rebuild.

Beneath the top-level HMI paradigm, several techniques were used to guide discussions and drive the HMI process. Particularly, methods evaluated and probed for information in order to determine cause and effects within the complex joint cognitive system. These cause and analysis methods were used during weekly meetings with a joint cross-functional team. These frameworks included (1) Five Whys analysis, (2) Brainstorming techniques, and (3) Ishikawa (Fishbone) diagramming as has previously been used in reduce errors in a manufacturing setting (Dziuba, Jarossová, & Gołębiecka, 2014). Root cause analysis can be an effective counterpoint, or substitute, for time consuming training endeavors to reduce causes of process errors (Murray, 2017). These methods are fairly easy to administer to novice users and can lead to important insights (Murray, 2017). Further, the collaborative nature of these approaches can lead to greater team buy-in for submitted solutions (Murray, 2017).

VI. Outcomes

The outcomes from the project were both a conceptual design and particular system insights. The HMI and enabling paradigms facilitated modeling the current system using a swim-lane diagram to understand the system, as well as several Ishikawa diagrams to note system cognitive gaps and the causes of manual interventions. Additional company specific insights were also developed. One critical determination was the cause of manual interventions, as noted in Figure 2.

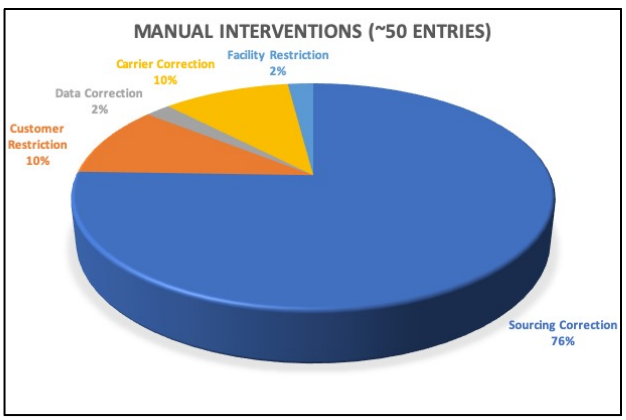

Figure 2 – Sources of Manual Interventions

Further, as shown below, a conceptual model for a complete system retrofit was developed through the pilot design process for the Company. The conceptual model shows both the steps to implement a HMI process and the iteration cycles for employing the system.

VII. Contributions

First, this research uniquely applies HMI frameworks to a specific loosely-coupled planning system. The contribution is novel at several levels of abstraction – from the view of a loosely coupled system in general down to a specific freight planning system in particular, as well as intervening layers of abstraction. Second, the use of enabling frameworks to augment and implement HMI architectural frameworks is an original contribution. This is generally novel as well as original in the particular application of those specific frameworks employed. Third, the development of a holistic iterative system that spans the conceptual and application levels is an innovation. For example, in Figure 3, a holistic concept to application approach is proposed.

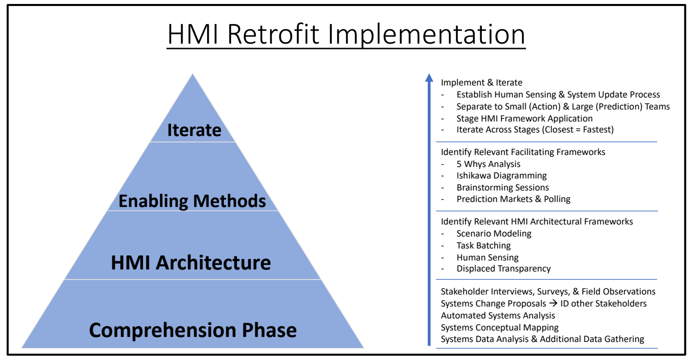

Figure 3 – Concept to Application Diagram for HMI Retrofit Implementation

Fourth, the proposal of a specific pathway towards implementation along with an iteration schedule is an original contribution. In Figures 3 and 4, that complete process is detailed. Figure 4 further depicts the suggested rates of iteration based on the level and scope of learning. For instance, a complete system understanding should only be refreshed on an annual basis, wherein system conventions and beliefs are critically challenged across the joint cognitive system. However, for small system impacts, such as changes to specific bits of system data, a daily or weekly iteration cycle is proposed. Intervening levels of abstraction merit different iteration cycles.

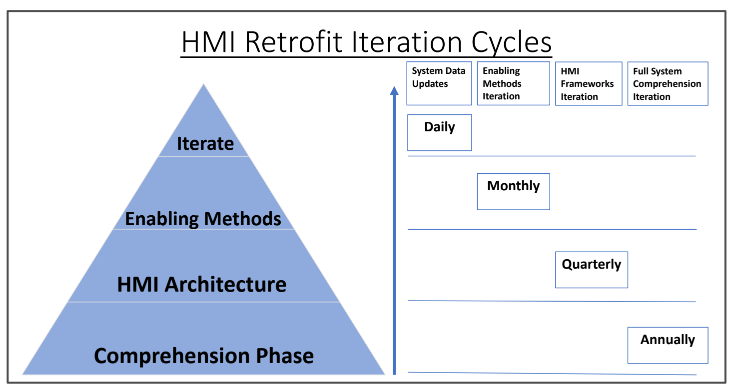

Figure 4 – HMI Retrofit Iteration Cycles

Fifth, the use of HMI and facilitating frameworks to *retrofit*, rather than cause a complete system rebuild, is an innovation in this context. Lastly, given the complete novelty of this HMI application to retrofit an existing loosely coupled planning system, particular applications and resulting insights are also unique.