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The Human-Centric Warehouse

Kevin R. Gue
Auburn University, kevin.gue@auburn.edu

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Auburn University, USA

Abstract

In theory and in practice, the objective of warehouse design has long been to meet operational requirements of throughput and service performance at minimum cost. A natural product of this "bottom line" approach has been warehouse buildings and operations ill-suited to the humans who spend their working lives interacting with them. We offer an explanation for the current approach, and argue that a new approach— a new *paradigm* —is needed. We then describe a comprehensive approach to warehouse design that includes human well-being as a primary goal.

1 Humans matter

"If you were to build a warehouse in which your children had to work, what would it look like?"

This simple question brings into sharp focus the human aspect of industrial facility design. Warehouses and manufacturing plants are not just places where products are assembled, stored, and shipped; they are also places where millions of people spend their working lives.

The conventional approach to facility design, taken by most researchers of industrial engineering, assumes there exists an "objective" objective function, which can be optimized subject to some constraints. In the material handling community, typical objective functions are throughput, cycle time, travel distance, and other financially oriented *performance* metrics. The bottom-line approach is attractive because it leads readily to mathematical and computer models, which usually provide objective measures for design choices: "A has higher throughput than B, therefore we choose A." The effect of such design choices on the humans that must live with them is rarely considered.

The actual practice of warehouse design may not be much better. Canterbury [4] describes a typical design-build process for industrial warehouses in which the financial requirements of the distributor are paramount. Although the study is far from comprehensive, the cited interviews with consultants and interior designers suggest that workers do not fare well in the design of the building and of the material handling systems inside. None of this is surprising, given that the firm is making the investment, and not workers directly.

How did humans come to be ignored in the design of buildings they would someday inhabit? We believe there are two main reasons. First, those who design the workplace (investors, architects, building contractors, material handling consultants) are not sufficiently familiar with or sympathetic to those who perform the work tasks, and they seldom have to live with the consequences of their designs. This disconnect in the design process leaves

workers and managers to deal with design choices they had no part in. They are simply expected to make due with the environment they are given. Second, those who design the work tasks ignore, for the most part, the well-being of workers, whose concerns are typically sacrificed to financial concerns such as Return-On-Investment. Whatever concessions are made to the workforce are usually justified in financial terms: e.g., safety systems are installed because otherwise worker compensation claims would be excessive.

If warehouses are unattractive places to work (an assertion which still requires empirical support, we admit), why should a distributor care, so long as costs are low and operational requirements are met? In a highly-competitive, global marketplace, this is certainly a valid question. We believe there are economic, social, and environmental reasons to design and build more *human-centric* warehouses. On a purely economic level, there are at least two reasons: (1) high turnover among warehouse workers [14] increases costs, and (2) if the anticipated shortage of skilled workers [21] comes to pass, warehouses will be competing for the services of workers, rather than the other way around. On a social level, we believe without apology that companies owe it to their workers, and to humanity at large, to create the best possible environment for their people. The progress of humanity ought not to be confined to fields such as medicine, psychology, and the liberal arts. On an environmental level, social and governmental pressure to build more sustainable facilities is leading many firms to consider more environmentally-friendly facilities, which create an image of social consciousness. Human-centric facilities are a natural extension of this idea.

The goal of this paper is to offer a possible explanation for how we came to ignore the human element in warehouse design, and to propose a framework for defining and creating human-centric facilities in the future. The framework includes four broad and interrelated areas, which, we contend, operate in research and developmenal silos. Progress in human-centric design will require coordination among these multiple areas.

2 Our current paradigm and its implications

In his classic work on scientific paradigms and the nature of scientific revolution, Kuhn [12] argues that progress in an academic discipline is possible because the research community is committed to shared beliefs about what are the valid questions, objectives, and methods of investigation in the field. Those not adhering to the existing *paradigm* are ignored or marginalized, but this is not a bad thing, necessarily. For any progress to be made at all, Kuhn argues, there must be a foundation upon which one is allowed to build.

Kuhn goes on to show that although paradigms serve as the foundation for scientific progress, no paradigm is sufficient to answer all the interesting or necessary questions. For example, Einstein's theory of relativity answered questions that the paradigm of Newtonian physics could not, thus establishing a new paradigm, and a way to answer new questions.

For our purposes, Kuhn's work shows, first, that paradigms exist and that they have a profound effect on what problems a research community considers valid and what ap-

proaches it takes to solve them. Second, paradigms tend to persist for decades or even centuries, and therefore they can be difficult to recognize.

The fields of industrial engineering and scientific management can be said to have begun about one hundred years ago, after publication of the pioneering works of Frederick Winslow Taylor [20] and Frank and Lillian Gilbreth [see, for example, 9]. Although the goal of these publications was unapologetically to increase worker productivity, humans and their work habits were the center of study. Bailey and Barley [1] document the steady decline of the study of work in industrial engineering departments during the past century. They observe that after World War II, the study of work was replaced by more mathematical sub-disciplines such as optimization and stochastic modeling, and by primarily laboratory-based ergonomics. The shift occurred for two reasons: (1) unlike field-based research in scientific management, mathematical modeling was more "academically respectable," and therefore helped to justify industrial engineering as a valid field of study; and (2) funding for these sub-disciplines was plentiful. They conclude that, although the nature of work and work systems has changed since World War II, the curricula and research in industrial engineering has not changed in response. They call for engineers to join social scientists in a return to field-based study of modern work systems. The ideas put forth in the present paper are consistent with this view.

With the works of Kuhn [12] and Bailey and Barley [1] as background, and with the subject of warehouse design as our object, we ask, "What is the current paradigm for research in warehouse design?" We believe it is comprised primarily of the following elements:

1. *Valid problems are those whose solutions benefit management or shareholders directly.* The names of premier journals in our field suggest such a bias: *Management* Science, Manufacturing and Service Operations *Management*, Journal of Operations *Management*, and so on. Subdivisions of *IIE Transactions* (Design and Manufacturing, Scheduling and Logistics, Operations Engineering and Analysis, and Quality and Reliability Engineering) mostly contain articles of technical design and analysis, which are primarily in the interests of the firm. A notable exception is research in ergonomics and safety, which is concerned with the physical well-being of workers in particular.

2. *Valid objective functions are financial.* This assertion follows almost directly from the first. Because the charge of management and the interests of shareholders is primarily Return On Investment, the objective of research that benefits them is most often maximizing profit or minimizing cost. Ergonomics and safety are again the exception.

3. *Valid methodologies are quantitative, primarily mathematical.* Bailey and Barley [1] provide a compelling explanation for this claim, which a scan of academic journals in industrial engineering and operations research readily supports.

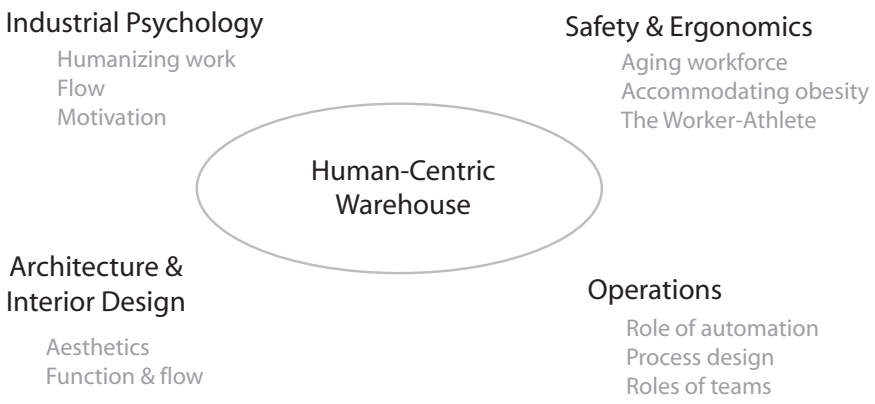

Figure 1: Major areas for development of a human-centric warehouse.

4. *Only contributions to a single, acknowledged academic discipline are recognized.* Multi-disciplinary research is notoriously difficult to publish, because academic journals are almost exclusively tied to a specific discipline. Therefore, such research is implicitly discouraged.

The current research paradigm grew out of post-World War II interest in mathematics and physics, which was at the forefront of post-war reconstruction and the Cold-War nuclear era. In a sense, industrial engineering was applying the latest developments of science to the domain of industrial activity. By contrast, today's most important fundamental discoveries are in biology, neuroscience, computing, robotics, and energy. What new paradigms for warehouse and material handling systems design might, or ought to, emerge in response?

3 Salubrious Design

To establish the context for human-centric design, we define a *work experience* as the execution of *work tasks* in a *workplace*. Work tasks include all of the activities normally associated with a job, such as material movement and processing, administration, and required interaction with other workers. A workplace includes the building in which tasks are done, temperature, lighting, and the corporate culture created by the firm. Both the work tasks and the workplace are products of design, and as such can be differentiated from wages, benefits, and other forms of compensation, which are easily changed by management. Design attributes are typically established before workers ever arrive to a new warehouse, and are not easily changed. To create an ideal work experience, we must design both the tasks (i.e., the job) and the place (the facility) in which those tasks occur, and these designs depend on one another. Figure 1 illustrates the areas we believe are critical to human-centric design.

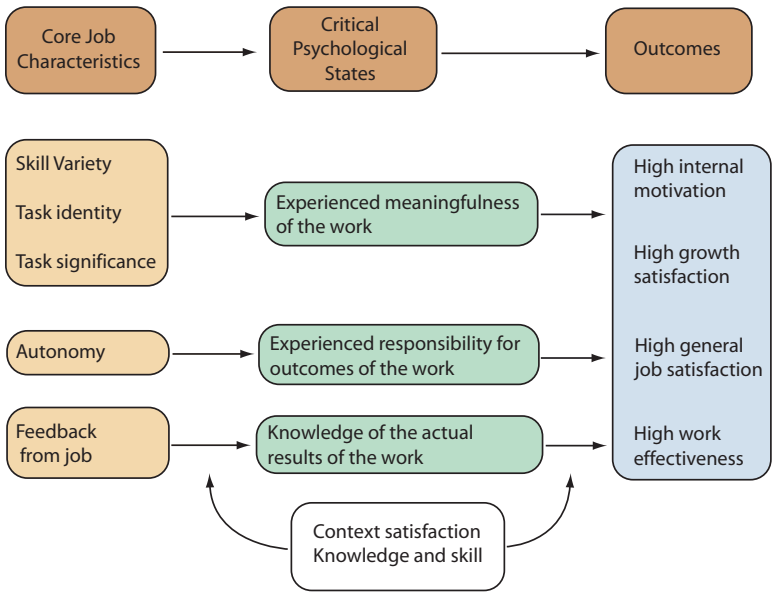

Figure 2: The Job Characteristics Model [10].

3.1 Industrial Psychology

Perhaps the most important of all disciplines to the development of human-centric facilities is industrial psychology, which investigates the behaviors, attitudes, and performance of workers in the workplace. One might even say its goal is to study work experiences.

There are several widely accepted theories in industrial psychology that might be brought to bear on the problem of human-centric design. Hackman and Oldham [10] developed the Job Characteristics Model, which proposes several attributes of a work experience that constitute satisfying work (see Figure 2). Many of these attributes have important connections to other areas in the human-centric design model. For example, the desire for skill variety is consistent, in the world of operations design, with worker cross-training and dynamic worker allocation schemes. The need for workers to receive feedback directly from the job (and not from supervisors), suggests there are benefits to workers being able to check the quality of their own work. It could also have implications for the design of the building (are workers able to see their work reach its destination?). The desire for task autonomy seems inconsistent, for example, with highly directive order picking systems such as voice directed picking. Do such technologies, in fact, lead to decreased levels of job satisfaction?

Czikszentmihalyi [6] has developed a significant body of work around the concept of *flow*, which he describes as "the process of total involvement with life." His research indicates that people are happiest when in a state of flow, which can range from intense athletic competition to reading to concentrating on a research problem. Given that workers "in flow" are more likely to be satisfied with their work, work processes might be redesigned

to facilitate these experiences. Or perhaps the building itself, and the layout of material handling systems and workstations, ought to be designed to facilitate such experiences. For example, many of the newest order picking workstations require extreme levels of concentration. Do these work experiences facilitiate flow, and therefore increased levels of job satisfaction, or do they create monotonous, stressful work experiences and therefore decreased levels of satisfaction? Should the layout facilitate individual tasks done without interruption?

Research in High Performance Work Systems [15] suggests that satisfaction increases when workers have greater control over their own work experiences. An extreme version of self-determination is the management system at Semco [19], which is modeled after democratic government. Workers determine their own hours, processes, and even their own supervisors. Can such theories be successfully implemented in a warehouse? What would be the implications for worker satisfaction?

Example research problem Redesign work processes in a distribution center in light of the Job Characteristics Model of job satisfaction. Measure satisfaction before, during, and after the changes to assess results.

Example research problem Build agent-based models of warehouse workers and operations to determine the potential productivity benefits (or costs) of self-organizing work teams and self-interested workers. Validate findings in the field.

3.2 Ergonomics, Safety, and Health

A comprehensive approach to human-centric warehouse design must include ergonomics and safety, of course, but it should also promote positive physical and health outcomes rather than simply avoiding the negative effects of poor design.

Conn et al. [5] argue from a meta-analysis of research on physical activity in the workplace that several positive outcomes are associated with physical activity, including improved fitness, higher job attendance, and reduced job stress. In another meta-analytical study, Pronk [16] says that "Comprehensive, multicomponent worksite programs that include physical activity components generate significant improvements in health, reduce absenteeism and sick leave, and can generate a positive financial return." Pronk and Kottke [17] advocate for corporate programs of physical activity for the benefit of the business. These are just a few of hundreds of research studies on the role and benefits of physical activity on worker welfare. Granted that these particular studies investigated mainly workplaces in which workers are sedentary, which is far from the case for many jobs in distribution, but they do help to establish the obvious: jobs with no physical activity are not ideal for workers or for the firm. We venture to add the equally obvious: overly strenuous jobs are also not ideal. Assuming for the moment, then, that there is some ideal range of

physical activity during the workday, how ought operational processes, work schedules, and job rotations be arranged for maximum benefit of the worker and the firm?

Example research problem Given a profile of ideal physical activity and rest, design operational processes, worker schedules, and job rotations that maximize (or balance) productivity and worker well-being. Validate findings in the field.

3.3 Operations

With respect to warehouse design, industrial engineering has traditionally had the most to say about the design of processes, internal storage, and material handling systems, all of which play a significant role in worker satisfaction. The level of automation, in particular, has a profound influence on the types of work tasks involved in warehousing. A human-centric warehouse must consider how these choices define the types of work in the facility. On this point, we are not advocating for warehouses designed *exclusively* for worker satisfaction, but rather for warehouses that provide both extremely satisfying work experiences and high levels of operational performance. We believe these goals are not mutually exclusive.

The vast majority of existing research on operational problems treats workers as "constant rate production machines," or, in more sophisticated models, as "stochastic production machines." Granted, these approaches have led to many significant advances in the design of systems and operations, but how those advances have affected work experiences is an open question.

For example, Bartholdi et al. [2] report significant increases in productivity after implementation of bucket brigades on an order picking line. They also report that "the pickers claim to be more satisfied because they prefer working in teams." This is a nice example of a system that increases both productivity and satisfaction.

The design of order picking and packing workstations also has implications for job satisfaction. Recently developed workstations by Knapp, Vanderlande, and several other companies boast pick rates in excess of 1,000 picks per hour. Many of these companies have put significant effort into making sure these workstations are ergonomically-friendly and not likely to cause repetitive motion injuries, but has anyone asked, "Would a worker really *want* to work at 1,000 picks per hour?" Or might the benefit of increased pick rates be offset or even overcome by increased turnover of workers assigned to this work? We do not know the answers to these questions, but they are of a sort that must be asked if we are to make warehouses attractive places to work.

A final example of the connection between worker satisfaction and operations design is a positive one. The Walgreen's distribution center in Anderson, South Carolina, USA was designed from the start to accommodate the special needs of a disabled workforce. About 40 percent of the workers in this DC have physical and psychological disabilities.

Walgreen's worked extensively with its warehouse management and material handling systems providers to ensure that its future workforce could operate the equipment and navigate its spaces successfully. This process involved many interations of design and testing with workers [18]. The result is a highly-accommodative human-centric warehouse, which has since been duplicated at another Walgreens site.

3.4 Architecture and Interior Design

Architecture and interior design are the primary disciplines that determine the workplace in which work tasks are done. Few would deny that buildings have an effect on the emotions, attitudes, and perspectives of their inhabitants. Anyone who has walked into a grand European cathedral, or into a dark medieval prison, can testify to the connection between architecture and emotion.

Recent developments in neuroscience promise, in time, to explain exactly what it is about certain design features that cause different emotions and attitudes [7]. Such insights could lead to guidelines for the design of industrial facilities such as warehouses. For example, Meyers-Levy and Zhu [13] report that high ceilings are more conducive to freedom-related activities such as creative thinking, whereas low ceilings are more conducive to item-specific activity that requires focus and discrimination. Color is another example: it is well-known that red generally creates feelings of arousal and tension, whereas blue causes more calm, peaceful reactions [3]. Which colors might be most conducive to productive, satisfying warehouse work? Making "correct" choices in this area adds essentially nothing to the cost of a facility.

Edwards and Torcellini [8] cite dozens of studies reporting the health and productivity benefits of natural lighting. Some recently built factories have made extensive use of natural lighting (see Figure 3), but almost no distribution centers have windows, in the author's experience.[1] How might extensive natural lighting in a warehouse affect job satisfaction and productivity?

In the realm of warehouse design, the disciplines of architecture and facility logistics have extensive overlap, yet there is, in the author's opinion, effectively no interaction at the design stage between building designers and, for example, material handling consultants.[2] Anecdotal evidence in Canterbury [4] supports this claim. Such coordination could yield facilities that are both aesthetically pleasing and highly productive. The relationship between work*place* and work *processes* was also explored by Horgen et al. [11].

Example research problem Determine the shape and internal layout of a warehouse that optimizes material flow, subject to no worker ever being more than a specified distance

[1] Some warehouses do admittedly have skylights, but we suspect the motivation for their installation is almost always financial.

[2] The author once suggested to a practitioner audience that architects and material handling systems consultants should work together before the building was built. The reaction was laughter.

Figure 3: Two innovative factories. The Herman Miller "GreenHouse" factory in Holland, Michigan (left), makes extensive use of natural lighting to provide workers a sense of connection with the outdoors. The Volkswagen "Transparent Factory" in Dresden, Germany (right) has Canadian maple floors and an almost entirely glass exterior.

from a window to green space.

4 Obstacles to Progress

Building a warehouse that is both highly productive and that provides highly satisfying work experiences is an enormously complex task, involving multiple disciplines that traditionally do not work together. We believe making progress in human-centric design will be difficult for a number of reasons.

1. As we have tried to demonstrate, a truly human-centric facility will require multiple disciplines to work together toward a common goal. The difficulties of this type of research are well-known and formidable.

2. Most required methodologies are experimental and field-based, not mathematical, which limits outlets for publication and probably the rate of publication. Field-based research simply takes time. Therefore, attracting industrial engineering researchers, who are traditionally interested in the domain area, will be difficult.

3. The objective of human-centric design is itself difficult to measure, and it is certainly not strictly financial. Therefore, achieving measureable outcomes— absent rapid developments in neuroscience, for example —will be difficult to claim.

4. Workers are the primary beneficiary of the topic, not management. Therefore, sources of funding will likely be difficult to secure.

In other words, research and development of human-centric facilities is not consistent with the existing research paradigm.

A possible path forward is for a progressive company to build a prototype human-centric warehouse, which could serve as a laboratory for design and experimentation. Workers would be fully aware that they are working in such an environment, and would be cooperative in research studies. The company would be willing to try new things and fail occasionally, in the spirit of learning and growth. Whatever the path it takes, future development must be grounded in the field, where real humans work in real warehouses.

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