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HUMAN FACTORS CONSIDERATIONS IN THE DESIGN OF AN AIRCRAFT MAINTENANCE HANGAR

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Many human factors issues in aircraft maintenance are directly related to the technicians' working environment and can be addressed in the maintenance facility design. The goal of this project was to identify and catalog human factors issues that should be considered from the outset in the design of a new maintenance facility for the Institute of Aviation at the University of Illinois. Towards this end, the structure and functionality of the existing hangar was examined, the technicians were interviewed, and their tasks analyzed. Based on these data as well as results from link- and activity relationship analyses, human factors requirements were listed for each functional area of the proposed facility. A suggested layout for the new facility represents an optimum relative arrangement of the workspaces, positioning of the aircraft in the main hangar, and the flow of tools, materials, and documents within the facility from an explicitly human-centered perspective.

INTRODUCTION

The aircraft maintenance hangar of the Institute of Aviation at the University of Illinois at Urbana-Champaign (UIUC) is old, not originally designed for its purpose, and going to be replaced by a completely new facility. To improve the maintenance technicians' working environment and to rectify poor ergonomics presently associated with many of their tasks, a project involving a group of volunteer students, enrolled in an undergraduate, introductory human factors class at the UIUC, was undertaken. The goal of this project was to identify and catalog human factors issues that should be considered in the design of the new maintenance facility from the outset. Towards this end, the structure and functionality of the existing hangar was examined, many of the numerous tasks of the technicians analyzed, and interviews of the technicians conducted. Based on these data, preliminary human factors requirements were listed by the specific areas of the new facility. Additional analyses included link analyses for 50- and 100-hour inspections of Piper Archer aircraft, which are the primary aircraft type in the Institute of Aviation's fleet, and an activity relationships analysis. These analyses provided further guidelines for the relative arrangement of the workspaces, positioning of the aircraft in the main hangar, and the flow of tools, materials, and documents within the facility.

THESIS

The maintenance facility has five major functional areas: the main hangar, parts room, engine shop, avionics shop, and the main office. In addition, a machining shop and a paint shop must be accessible to the technicians. These areas have a number of unique characteristics and warrant different human factors considerations. Because of the multiple constraints involved in the design and high cost of construction of a new maintenance facility, it is imperative that the human factors considerations are laid out at the earliest stages of the facility design process. The analyses and conclusions reported in this paper seek to accomplish just this: To provide clear guidelines and specifications for the architect of the new facility to abide by and to facilitate incorporation of good human factors in the final design of the facility.

SOURCES

This project was completed in two distinct phases. The first phase concentrated on listing potential human factors issues in the hangar design and identifying existing ergonomics problems in the technicians' tasks and working environments. This information was gathered from in-depth interviews of the aircraft maintenance personnel and through task analyses on selected tasks. Since the technicians' tasks are long but typically performed in a step-by-step fashion, their components lend themselves to the activity sampling and flow chart methods of task analysis (Kirwan & Ainsworth, 1992). The results of these analyses were then converted, essentially, to questions for subsequent interviews. These interviews provided a set of "wish lists" for the design of each particular area in the maintenance facility. Link analyses helped further to identify existing human factors problems associated to various aircraft maintenance tasks and to optimize the subsequent design suggestions for the new facility.

Based on the findings from the first phase, an activity relationship analysis was performed to arrive at overall guidelines for optimal locations of the different areas in the facility relative to the main hangar floor and each other. The activity relationship analysis is a qualitative study of the adjacency relationships through the use of activity relationship charts, commonly know as REL charts. The purpose of the REL chart procedure is to quantify the objective opinions of the facilities primary users and then utilize this information to help create a more user-friendly design recommendation. Finally, review of a number of human factors handbooks yielded design guidelines for specific details (Bailey, 1989;

Salvendy, 1997; Sanders & McCormick, 1993; Wagner, Birt, Snyder, & Duncanson, 1996; White, & Churchill, 1971; Wickens, Gordon, & Liu, 1998).

FINDINGS

The Main Hangar

The main problem with the existing hangar is the fact that only one plane can be moved in and out of the hangar at a time. Several aircraft often have to be moved to pull one finished plane out through the door, disrupting work. Other problems that were identified include too dim lighting, in particular when working in confined spaces (the technicians frequently must look for a flashlight even when all the lights are on), the present door system is not acceptable (the door often gets stuck, is loud, and drafty), floor drains are needed so that the technicians would not have to continuously wash the floor and carry around pans of aviation fluids from one spot to the next, and a loud compressor that prevents conversation between technicians only few feet apart. The heating of the hangar was also found to be unacceptable (an underfloor heating system was suggested). The placement of the machine shop, parts, and avionics relative to the main hangar was deemed acceptable, but as the overall design of the hangar depends on the position of these areas, an integrated approach to the problem should be adopted. Finally, oil disposal by a forklift in the present hangar is a safety hazard and inconveniences the mechanics.

Parts Room

Parts for seven plane types are being stocked presently, in addition to backlogged parts from aircraft that were owned by the university in previous years. Parts stocked included all sorts of screws, bolts, and fasteners, chains, metal tubing, sheet metal, engine parts, propellers, and oil and gas drums. Some of these parts are stored in jars, other frequently used parts are stored in small bins. There can be anywhere from 10 to 500 small parts kept on hand, depending on the current state of the inventory and the throughput of the part. Larger parts such as metal tubing and sheet metal are stored in the main storage room as well. Propellers and various engine parts are scattered about the main storage room and the paint and oil room. The current system of organizing the parts on the shelves is such that the part number increases as one goes from left to right on a particular shelf, and increases as one goes from top to bottom of the shelf. This appears to be a superior method of arranging the parts, as opposed to organizing them by category. This allows for anyone, not just the parts room manager, to find a part.

Engine Shop

The engine shop is located right next to the parts room. The shop structure works well for a complete engine overhaul since the engine has to go through the work areas in order. This follows the sequence of use principle, but there are two major problems with this structure: When the engine overhaul is complete, the engine must be brought back all the way through the other rooms to the front. Furthermore, not every engine that comes in needs a complete overhaul, but may only need to use one of the areas in the shop. Other human factors problems identified include only one fan in the back room that ventilates the entire shop. More fans are needed to keep fumes and particles out of the air. The shop's temperature control was also deemed to be inadequate and lighting too dim for most tasks. Finally, lead levels in the shop were high, possibly due to inadequate ventilation.

Avionics Shop

The main function of the avionics department is to complete the repairs and updates of the radio devices in the aircrafts. Most of the work on avionics (about 70%) is done in the shop area, whereas only 30 % is done at the plane. This characteristic sets high standards for the ergonomic design of the shop. The problems identified in the existing shop ranged from ergonomically dangerous working postures when uninstalling and installing equipment in the airplanes to fixed-height workbenches, reach height of some of the components, and height of the electrical outlets (near the ceiling, approximately seven feet high). The design of the shop is also constrained by the FAA regulations (e.g., for altimeter work).

Main Office

Evaluation of the main office revealed many ergonomic problems associated with standard office furniture and equipment. In addition, the location of the main office relative to the other areas in the facility is important because of the requirement for accessibility of records and manuals by everybody working in the facility. Better organization of microfiche materials, perhaps in a dedicated room with a computer which holds links to airworthiness directives (ADs) and FAA Regulations, taps into the dispatch switch board, and maintenance schedule and log information (central computer idea). A dedicated office space for the technicians, including the microfiche library, additional in-room computer station for more intensive research or checking e-mail, and where workers could have their own phone to use.

Activity Relationship Analysis

Due to the nature of the work done in a maintenance hangar it is essential to study the importance of the relationships between both from a quantitative and qualitative standpoint. The former was accomplished by the link analyses and the latter through the use of activity relationship charts, commonly know as REL charts. The purpose of the REL chart procedure is to quantify the subjective opinions of the facilities primary users and then utilize this information to help create a more user-friendly design recommendation.

Data acquisition: The REL chart represents the importance of adjacency between departments using a six-level rating scheme as follows: Absolutely necessary (A), Especially important (E), Important (I), Ordinary Importance (O), Unimportant (U), and Undesirable (X). In our study all facility users were given the opportunity to assign these values as they saw fit between each of the seven departments within the facility. The REL chart was represented by the inputs of an upper triangular matrix where each department represented both a row and a column. Therefore each entry represents how the user rated the importance of adjacency between the department in that row and the department in that column. The analysts were instructed to assign only a limited number of these ratings in the REL matrix. More specifically they were asked to only use 1-2 A's, 1-2 X's, 3 E's, 4 I's, 6 O's, and 14 U's. However these were only suggested approximations to force the analysts to clearly differentiate between departments and to aid in the analysis of the data. In addition to a letter rating to each adjacent department, the operators were also asked to explain the reasoning behind why they felt those departments necessitated a high importance rating or conversely a low or undesirable importance rating.

Analysis. After all eight REL charts were completed by different facility users this data was then analyzed to help generate possible facility layouts. The first step was to assign numeric scores to each of the ratings used in the REL chart. The scale and score for these numeric equivalences is listed on all of the individual REL charts and is as follows: A=64, E=32, I=16, O=8, U=4, and X=-100. These values were assigned by the analyst in an attempt to amplify the importance of an A and E relationship and to highlight any infeasible or undesirable X relationships. The numeric values were then averaged across all of the surveys into a new REL chart representing the compilation of the eight individual results (Table 1a.).

Table 1a. and 1b. *Averaged results of the Activity Relationships Analysis of the UIUC aircraft maintenance hangar.*

a.

	H	S	E	A	P	B	W	O
H		54	34	19.5	-31.5	20.5	28	53
S			40	10	-34.5	7.5	-5	19
E				4	-34.5	6	10.5	18
A					-47.5	5	-22	15.5
P						-14.5	-21	-46
B							-5.5	6.5
W								-21
O								

b.

Department	M(i)
Main Maint. Hangar (H)	177.5
Stock Room (S)	91
Engine Room (E)	78
Avionics Lab (A)	-15.5
Paint Shop (P)	-229.5
Break/Locker Room (B)	25.5
Weld/Sheet/Machine Area (W)	-36
Main Offices (O)	45

In this way we were able to eliminate some of the variation between users' rating schemes as the relative value of each score in relation to the others in that chart becomes more important than the specific value placed on each adjacency. Once the scores were averaged across every department adjacency, numerical scores were calculated for each individual department. This calculation was done by simply taking the sum of the averaged scores between that department and every other department. For example the stock room score was computed by adding together the scores between the stock room and the hangar, the stock room and the engine room, the stock room and the avionics lab, the stock room and the break room, the stock room and the welding/sheet metal/machining area, and the stock room and the office. The result of this calculation was a value of 91. Results for all of the other departments were calculated in a similar fashion and appear in Table 1b.

Results. The physical geometry of the maintenance facility and the results of this activity relationship analysis do not easily lend themselves to the simple application of a well defined facility layout algorithm (e.g., the deltahedron heuristic, the computerized relationship layout planning procedure CORELAP, or the computerized relative allocation of facilities techniques CRAFT). This is because a feasible aircraft maintenance facility must have a main maintenance hangar with access to the outside through a large hangar door which eliminates it from being surrounded on all sides by the other departments as would likely happen in a CORELAP or deltahedron procedure. The large size of the main hangar relative to the rest of the facility departments also makes it feasible to be adjacent with many if not all of the other departments a consideration that is rarely produced by any of these algorithms. Therefore, the best way that these data can be used is simply to make design recommendations. The high scores observed between the hangar and the stock room, the hangar and the engine room and the stock room and the engine room suggest that the design should try to allow for all three to be adjacent with one another. Similarly the paint room received a negative relationship between every department and therefore perhaps the design should try to isolate this department from the rest of the departments, save the main hangar, which it must be connected to for functionality. The sum score for the welding/sheet metal working/machining area was negative so a possible design consideration could be to completely isolate this area from the rest of the facility to reduce noise, odors, and air pollution. Other important observations reported by the users suggest that the avionics lab be close to the stock room because it would be "highly desirable for ease of operation." Similarly, other users suggested keeping the stock room and the office adjacent for "office functions between secretary, manager, and store keeper."

It is important to remember that it may not be possible to meet everyone's wishes perfectly. Therefore this activity relationship comparison should be used in tandem with the information observed in the link analyses in order to design a facility that best facilitates all of the workers needs and is designed for the best functional use between departments.

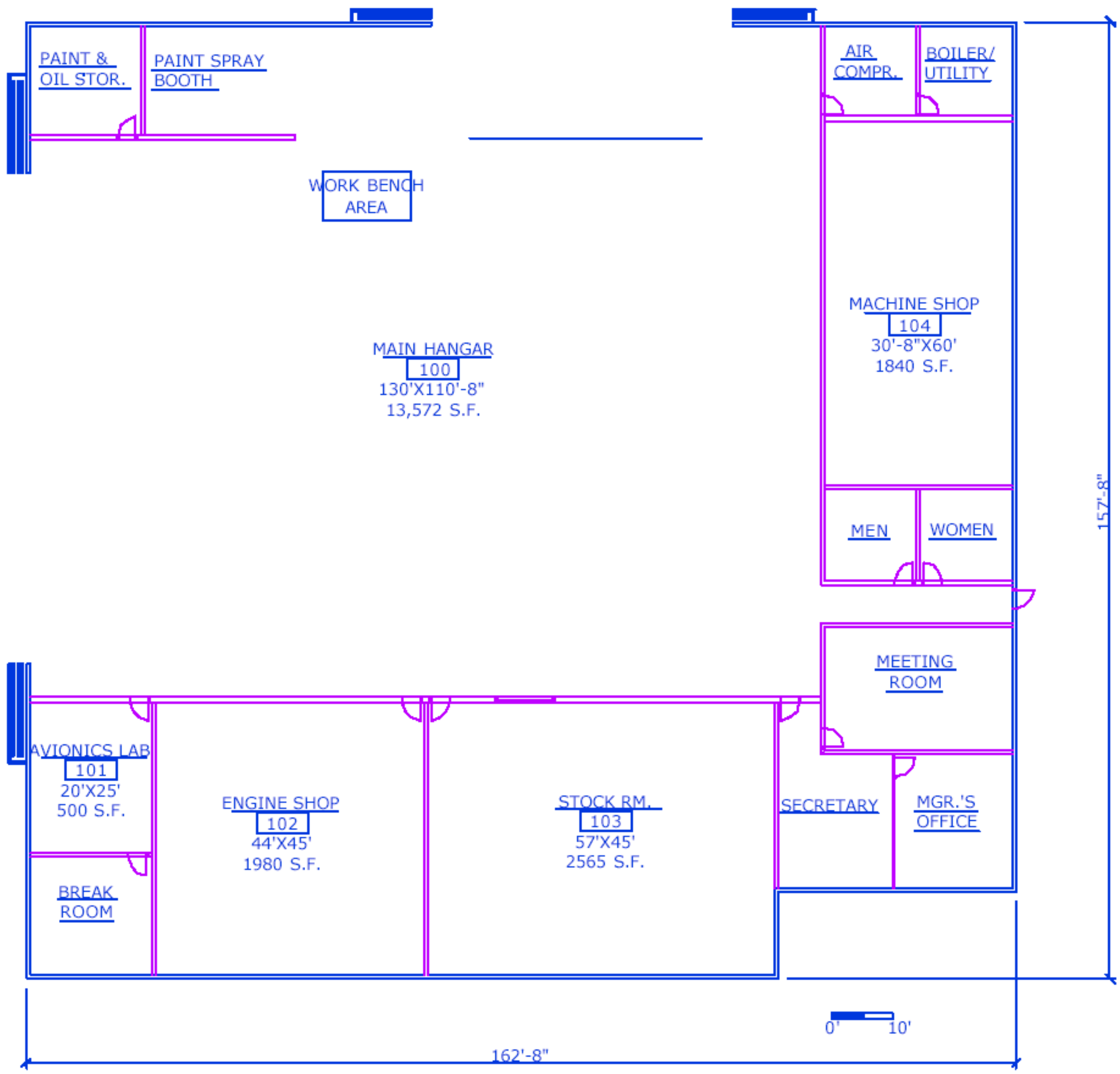

Figure 1. The proposed layout for the new aircraft maintenance facility at the Institute of Aviation at UIUC. The design is based on the human factors reviews and analyses performed during this project.

DISCUSSION

The results of this project appear in Figure 1. The new hangar layout is explicitly based on the preliminary data provided by the maintenance personnel with respect to the dimensions of the various areas and departments within the hangar, the data gathered though maintenance personnel interviews, and the activity relationships analysis and link analyses. The most important features in the design are the adjacency of avionics shop, engine shop, and stock room to each other, the main hangar floor, and the manager's office, and the isolation of sources of noise, air pollution, and hazardous materials (machine shop, air compressor, and paint and oil storage).

Further human factors considerations incorporated to the design include an easy access for a fork lift to the oil and paint room, hazmat storage room with a sunken floor to eliminate dangers of spills, shower area with face wash located with easy access to all parts of the shop in case of a hazmat spill, a wash station with power sprayer, air compressors insulated for noise reduction, insulated machine shop (to reduce noise and debris cause by machining), centrally located work bench to allow easy access from all work stations, improved heating, ventilation, and lighting throughout the facility, and multiple doors for moving aircraft in and out of the hangar. A clearstory above the main hangar floor is recommended for maximum amount of daylight in this area. In addition, all interior surfaces (floor, walls, and ceiling) in the main hangar are to be painted brilliant white for maximum light dispersion and reduction of shadows through indirect lighting.

Some design recommendations have already been incorporated to the old hangar: A new parts room labeling system was designed to the specifications drafted for this project. Now labels are typed instead of handwritten and contain both the number and the brand of the part. To take advantage of chunking, the first three numbers are followed by a space or two, making the part immediately recognized and identified as a Piper product. Furthermore, part labels are now color coded and mapped to the color-coding of the parts room. The shelves also have indexing labels that contain the range of part numbers that were located on that particular shelf. This index label is also color coded with the specific parts that are held on that shelf, allowing the user to scan for only one target, the indexing label, to determine whether or not the part is on the shelf. The aisles in the part room are labeled according to a color-coordinated map/layout of the parts room and the label placement is standardized by placing all labels on the shelving unit, in front, and below the actual parts bin. Physical ergonomics have bee addressed by moving heavier parts at waist high storage levels.

CONCLUSION

This project resulted in many valuable outcomes. First, the project offered an opportunity to integrate a real-world problem into an undergraduate human factors course. Success of this integration is evident in the performance of the students involved in it. All were very enthusiastic about their tasks, frequently exceeding the prescribed requirements, and clearly eager to apply the material covered in class. Second, close collaboration of the students and the aircraft maintenance personnel fostered mutual understanding and respect between different groups of the university community. The maintenance technicians were clearly grateful for the attention to their working conditions, and in particular the student pilots in the project group gained new appreciation for the maintenance personnel's efforts towards their safety. Finally, this was a very opportune time to conduct analyses and develop human factors specifications for the new hangar, before the building project is formally launched. We hope, therefore, that the results of this project can be incorporated in the eventual design of the new aircraft maintenance facility from the outset and that the benefits of good human factors can be realized as soon as the new facility becomes operational.

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