# Defect Distribution for Wearable System Design*

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## Abstract

*This paper describes a design process for custom wearable systems produced in an academic setting. A set of 245 wearable design defects from two distinct periods separated by six years in time is presented. These data identify aspects of the process requiring significant developer effort, which we show using an Orthogonal Defect Classification scheme. A comparison of defect attribute distributions across the two separate design periods is given. The results show that growing electronic complexity is increasing the number of defects caused by designer error, and that more defects are being observed in earlier phases of the design process.*

## 1. Introduction

The design requirements for a wearable system are a set of simultaneous constraints on electronics, software, mechanical design, and usability. It is sometimes difficult to satisfy these requirements using only off-the-shelf componentry. For these cases, some amount of custom design, implementation, and testing must take place.

This paper examines two periods of wearable system design at Carnegie Mellon, 1994–1996 and 2000–2002. We observe that not all of the increased capabilities of the more recent systems were "free" to the designers. Moore's Law has helped in some areas, such as memory density. Countering these gains, however, are interconnect and interoperability requirements, such as peripheral I/O standards and operating system support for new hardware. The design impact of these requirements can range from increased complexity in an existing subsystem, to the addition of entirely new subsystems. In some cases, there may be no prior experience in combining particular subsystems; this introduces risk which must be considered by project planners.

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## 2. Defect Attributes

In a wearable system development effort, it is useful to be able to predict the amount of time which will be consumed by design, build, and test. This is important for budget reasons as well as for scheduling the availability of finished systems to users. Some factors which contribute to development time are predictable or controllable; for example, manufacturing follows a simple function relating cost and delivery speed. Conversely, design complexity introduces delays in the form of *defects*, which can be difficult to anticipate.

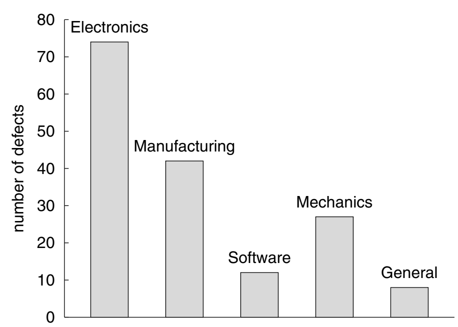


**Figure 1. Spot defect types.**

Wearable system design is a multidisciplinary process which incorporates electronics, mechanical or industrial design, and software. Figure 1 shows the distribution of 163 defects in the Spot wearable computer, on which development began in 2000. This organization is decomposed according to discipline, or *type*, and may be useful for predicting what kind of developer resources within each field might be helpful. Figure 2 defines the four design process phases in time — Design, Bringup, Integration, and Operation — and the per-discipline activities associated with each. The combination of defect *type* and *time* attributes is a basis for in-process defect analysis.

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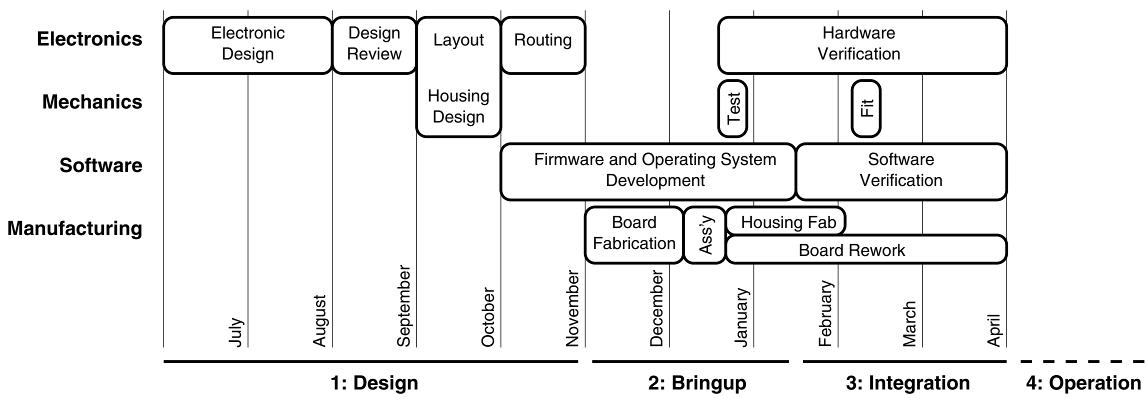
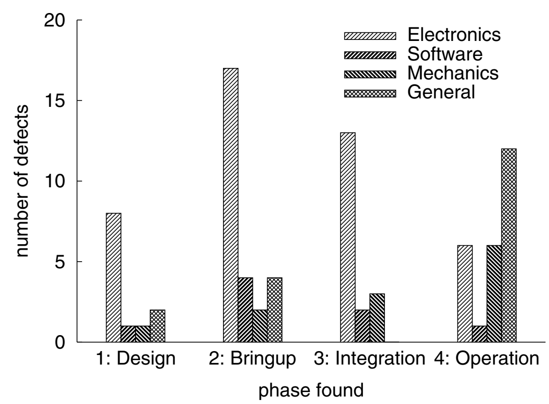



**Figure 2. Spot design process timeline.**

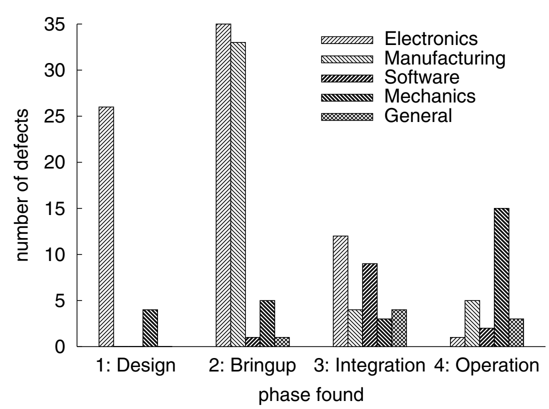
## 3. Orthogonal Defect Classification

We are refining a variant of the IBM Orthogonal Defect Classification system [2] for electromechanical systems [1]. Figure 3 compares 82 defects from an earlier design period (the Vū·Man 2R and Navigator 2 systems, 1994–1996) with 163 defects from the more recent Spot. Electronics defects peak in Bringup for both sets of data, but the Software peak has shifted from Bringup in the earlier data to Integration on Spot. Also, at least half of the Mechanical defects occur in the Operation phase for both sets. Increased resolution for hardware defects was provided in the Spot data by separating Manufacturing from Electronics. Manufacturing, which includes errors in fabrication, assembly, and rework, accounts for nearly half of Spot Bringup defects.

A similar comparison of the two design periods using other defect attributes has been performed. The ratio of *omission* defects to *commission* defects in the earlier work is nearly 1:1. Commission defects in Spot have more than tripled, bringing the ratio for the more recent work to 1:3.4. Additionally, the number of defect discoveries associated with a *new hardware* aspect of the design was distributed evenly across the last three phases of the earlier work. On Spot, more than half of new hardware defects were discovered in the Bringup phase. More results from this analysis are presented in [3].




(a) Vū·Man 2R and Navigator 2.




(b) Spot.

**Figure 3. Defect type distributions.**

## References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[2] I. Bhandari, M. J. Halliday, et al. In-process improvement through defect data interpretation. *IBM Systems Journal*, 33(1):182–214, 1994.

[3] J. G. Dorsey and D. P. Siewiorek. The Design of Wearable Systems: A Shift in Development Effort. Technical Report 18-01-02, Carnegie Mellon University Institute for Complex Engineered Systems, Pittsburgh, PA, 2002.