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THE OPTIMAL DESIGN OF HUNTING WEAPONS: MAINTAINABILITY OR RELIABILITY

Peter Bleed

Design engineers share archaeologists' interest in material culture, but unlike archaeologists, engineers have developed concepts for determining the suitability of technical systems to perform specific tasks. Given the difficulty archaeologists face in developing theories of material culture, I suggest that guiding principles of engineering design offer potentially useful insights.

In this article I discuss two design alternatives for optimizing the availability of any technical system—reliability and maintainability. Reliable systems are made so that they can be counted on to work when needed. Maintainable ones can easily be made to function if they are broken or not appropriate to the task at hand. Because these design alternatives have markedly different optimal applications and observably different physical characteristics, archaeologists can link the design of prehistoric weapons to environmental constraints and to specific hunting strategies. Ethnographic examples indicate that primitive hunters do use both reliable and maintainable systems in optimal situations.

Formal diversity of tools and tool assemblages has been the primary focus of archaeological research since the very inception of the discipline. Over the years archaeologists have found precise ways of describing and cataloging prehistoric artifacts and have learned to use variation in material culture to construct culture-historical frameworks. Description and interpretation of variation in the technological sphere has, thus, been critically important to archaeology. In recent years, though, consideration of formal and assemblage variation of artifacts seems to have passed out of vogue. First, culture historical research has become less popular so that the search for new and more refined horizon markers is generally seen as a fairly sterile activity. Beyond that, the major theoretical developments in archaeology of the last 20 years have been in areas that do not deal directly with material culture. Issues of subsistence and settlement patterns and the interpretation of ecofactual remains have made great strides while the macroscopic consideration of artifacts has languished. Some modern archaeologists have come to consider "material culture as the product of human categorization" (Hodder 1982:7) and have replaced attempts to understand the functional significance of artifacts with discussion of how they reflect social and symbolic structures.

A major reason that subsistence and settlement studies have flourished is because archaeologists working on those topics have been able to go beyond description of archaeological observations by using ideas derived from other fields. At the same time, archaeologists concerned with explanation of variability in prehistoric technology have been stymied by an essential lack of developed theory directly related to their topic. To be sure, attempts to develop such theory are moving ahead but progress is slow in part because none of our traditionally aligned fields has offered ideas that are easily relevant to material culture. If archaeologists are to explain diversity in material culture—which is, after all, the most important element in the archaeological record—we must either create or find ideas that will allow us to make sound inferences about the factors that shaped prehistoric artifacts and assemblages.

Because our traditionally aligned fields in the social and biological sciences have little expertise with material culture, it seems wise for archaeologists to begin looking into unsearched areas for

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ideas we might be able to use. One such area is engineering, one of the few fields that shares archaeology's interest in material culture.

In this paper I seek to contribute to archaeological theory by showing how specific guiding principles of engineering design can allow the hunting strategies and other behavior of prehistoric hunters to be inferred from the design of their hunting weapons. The specific concepts discussed are reliability and maintainability and they are applied to the interpretation of weapons used by simple hunters.

ARCHAEOLOGICAL AND ENGINEERING APPROACHES TO MATERIAL CULTURE

Although both engineers and archaeologists are interested in material culture, the interests and strengths of the two fields are different and in many respects complementary.

Archaeologists have developed very rich descriptive vocabularies and conceptual structures for the treatment of artifacts. Our ability to describe, classify, and trace the history of tools and other items of material culture is truly formidable. No other field comes close to our expertise in these areas. This virtuosity does not entirely mask some shortcomings of the field. Thus, for example, although archaeologists have begun to study patterns of tool production, use, and discard, we still know very little about the creative processes whereby artifacts are designed and made. Kleindienst and Keller (1976:184) have pointed out a second shortcoming, which is that archaeologists have not developed techniques for relating artifacts to work or to the tasks for which they were made. Finally, because archaeologists are entirely unused to evaluating artifacts in anything more than descriptive terms, we are not able to judge the quality or effectiveness of different kinds of artifacts.

Design engineers have scant interest in the problems archaeologists try to solve although they do have expertise in some areas of archaeological weakness. Because engineers are professionally involved in the process of creating technical systems, they have developed ways of conceptualizing the design process. Secondly, the activity of technical design has shown engineers that not all technical alternatives are equally good or equally effective in all situations. For that reason, engineers have developed ways of determining which of a number of design alternatives is superior in a given situation. With these ideas, they can evaluate alternatives to create designs that are optimal to a given problem. Such optimum designs maximize a significant desirable effect by achieving the best compromise between the costs and benefits of the total system. The ideas used by engineers to identify optimal solutions are generally parallel to optimization or maximization models used in biology, management, and other fields (see Jochim 1983; Smith 1978). They are potentially more attractive to archaeologists, though, because they are directly relevant to material culture. At least the ability of engineers to recognize situational constraints and evaluate technical systems in light of them are skills that archaeologists might wish to emulate.

SYSTEM DESIGN: RELIABILITY AND MAINTAINABILITY

A number of recent analyses have shown that rational optimization models used by ecologists and economists can be useful for describing the activities of primitive hunters (Keene 1981; Reidhead 1980; Williams 1981) especially if they are used judiciously (Jochim 1983; Keene 1983). Observations by anthropologists suggest that primitive hunters are similarly rational in the area of technology in that they make and use well-crafted, carefully designed tools (see Laughlin 1966:313; Oswalt 1976:36). In that sense, the weapons of primitive hunters can be compared to modern industrial systems like assembly lines, semi-trucks, or the space shuttle. The approaches taken to the design of modern technological systems, and the rationale for the selection of design alternatives in those systems, offer a context for the analysis of the primitive artifacts.

All technical systems result from a design process. This may be either explicit or implicit, but in either case, the designer selects from the available alternatives to create a solution to an identified problem. A design is, thus, a variable, because it can be altered by the selection of alternative components that either alter its effectiveness or change its applicability.

Because design is a variable, not all designs are equal or equally good. In fact, designs can be evaluated along many different dimensions—aesthetics, efficiency, cost, etc. (see Pye 1978:23–35).

Table 1. Characteristics of Reliable and Maintainable Systems.

Reliable systems:
1. Overdesigned components (parts made stronger than they minimally need to be)
2. Understressed (system used at less than full capacity)
3. Parallel subsystems and components—(redundant and standby)
4. Carefully fitted parts and generally good craftsmanship
5. Generalized repair kit including basic raw materials (to affect any repair)
6. Maintained and used at different times
7. Maintained and made by specialist

Maintainable systems:
1. Generally light and portable
2. Subsystems arranged in series (each part has one unique function)
3. Specialized repair kit that includes ready-to-use extra components
4. Modular design
5. Design for partial function
6. Repair and maintenance occur during use
7. User maintained
8. Overall easily repaired—"serviceable"

Minimally, a design must be "effective." That is, it should do the job it is designed for; a semi-truck should haul cargo to its destination, the space shuttle should make it in and out of orbit, and a bow and arrow should be able to strike and immobilize game worth taking.

A good design will be more than a minimally effective solution to a problem. It may have to be pretty, or meet with social expectations, or convey some social or symbolic meaning, but beyond all of this, the lesson of evolutionary selection is that a design must also be efficient. Certainly, efficiency is the major dimension along which technical systems can be objectively judged. Efficiency refers to the amount of output delivered by the system divided by the amount of input or "cost." In spite of its apparent simplicity, efficiency is a complex issue because it can be calculated in many different values—energy or material costs, body stress, time, etc. Design engineers can very precisely calculate efficiency for modern designs (see for example Middendorf [1969]). Even ecologists studying the behavior of animals can deal with fairly straightforward measures of efficiency (see Charnov 1976). For simple hunting weapons, though, efficiency is hard to approach because so little can be directly measured about production costs, use, and effectiveness.

One simple cost-related measure that is relevant to any system's overall efficiency is *availability* (Konz 1979:327–340; Ostrofsky 1977:180–181). Availability refers to the amount of time that a system is available to do its job. A designer can optimize the availability of a system with either of two strategies. First, a system can be designed to be *reliable*. It can be made in such a way that, come what may, the ability to function is assured. Alternatively, a system may be made *maintainable*. That is, it can be made so that if it is broken or not appropriate for the task at hand, it can quickly and easily be brought to a functional state. Both reliability and maintainability are strategies for making systems available when they are needed. They are dissimilar in that they have very different implications for the physical appearance of a finished design. They also have different costs of construction and applicability that make them appropriate in different situations.

CHARACTERISTICS OF RELIABLE AND MAINTAINABLE SYSTEMS

Some typical design characteristics of reliable systems are presented in Table 1 (Konz 1979:328–330; Middendorf 1969:242–262; Ostrofsky 1977:162–185). In general, these characteristics involve strengthening or increasing the size of the components of the system. A basic element in the reliability strategy is overdesigning the components—especially the most critical components—of the system. This means that key components are built solidly enough to easily withstand the stresses that will be encountered. Components of a system designed to be reliable will, therefore, tend to be sturdy. If size adds strength, they will be big. Careful fitting of parts, special attention to joints, and good craftsmanship in general will also be typical of an overdesigned, reliable system. Along with overdesigning, another means of increasing a system's reliability is understressing. This refers to using a system at well below its maximum capacity.

Reliable systems are typically built with both redundant and standby components (Middendorf 1969:255–258). That is, they have multiple components doing a single task. Redundant components operate in parallel and in the same way as one another. Thus two inspectors checking parts moving down an assembly line are redundant but increase the reliability of the inspection process. A quiver full of identical arrows would be redundant as would be a multi-point fish spear. Standby components also operate in parallel but as backups to other components and come into use only when some other component is not successful. Examples would be an aircraft escape hatch that could be opened hydraulically, manually, or, failing all else, with an explosive charge. A bowman with a spear, in front of a net impoundment, would also be operating with standby systems.

In addition to these design characteristics, reliable systems also have some special characteristics of operation. First, set-up and maintenance activities of reliable systems tend to be markedly different from times of use. This usually requires that maintenance and use be carefully scheduled in advance. Second, the reliable systems tend to be made and maintained by specialists so that the operators of these systems are often not able to repair them. Finally, maintainers of reliable systems work with generalized repair kits and tools capable of handling any problem. Because the systems are not supposed to break down, problems may occur unpredictably and in any part so that repair personnel must be prepared to make or repair virtually any component.

The list of characteristics in Table 1 indicates that systems designed to be maintainable tend to be simpler than reliable ones (Konz 1979:329–331; Ostrofsky 1977:179–180). They tend to have a series design with each component made to do its own unique job. Thus, if any component fails, the whole system fails. At the same time, since points of failure can be predicted, maintainable systems have modular design so that failed components can easily be removed and replaced with a spare part that makes the entire system functional. Maintenance workers on these systems are typically equipped with a specialized repair kit that has spare parts and tools designed to effect specific predicted or anticipated repairs. One way maintainable systems are made to avoid total failure is to be designed for partial function. That is, they have some way of functioning—if not at full efficiency—even after some component fails. A six-cylinder engine can run with one or even two sparks plugs inoperative just as a bowman without arrows may be able to achieve partial success by using his bow as a spear.

Maintainable systems also have distinctive operational characteristics. Notably, there is typically not a clear and scheduled separation between the time these systems are in use and the time of maintenance and repair. They are fixed when broken and maintained as needed. Similarly, users of maintainable systems tend to be able—and equipped—to service them.

Maintainability and reliability are design alternatives that a tool builder can use to increase the availability of systems in different situations. They are not actually opposite points on a continuum, although in some cases there may appear to be some blending between them. First, because the importance of system availability can vary, the degree to which either maintainability or reliability is built into a system is also variable. Where availability does not matter, the system may not be markedly reliable or markedly maintainable. Secondly, one way of increasing the reliability of critically important systems is to design them to have all the basic characteristics of reliability *and* also to add features of maintainability. In that case, if the worst happens and the system fails when it is needed, it can be rapidly repaired for continued use.

OPTIMAL CONDITIONS FOR RELIABLE AND MAINTAINABLE SYSTEMS

Reliability would seem to be ideal in any system. In fact, though, reliability has costs that make it less than optimal in some situations. Standby and redundant components, as well as the overall overdesigning needed to assure the system's operation, make the construction of reliable systems

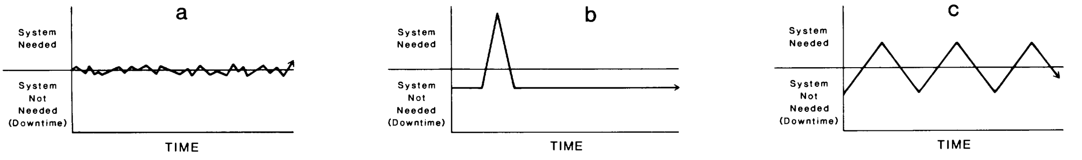

Figure 1. Hypothetical schedules optimal for maintainable (a) and reliable (b and c) systems.

costly—whether calculated in terms of money, time, raw material, or any other resource. They also make the systems bulky and, therefore, hard and expensive to move around.

The disadvantages—or added costs—of reliable systems can be justified only in situations where the advantages of increased availability outweigh the added design costs. Reliability is, of course, most necessary when the costs of system failure are extremely high as might be the case when an airplane can't get its wheels down or when a hunter misses some critical game animal. Situations which make it easy to predict when and for how long a system will be needed are also appropriate to reliable systems. Situations with predictable "downtime" might be anything from a changing work shift to an annual migration of game. If repair and maintenance activities can be done during predictable periods of downtime—when the system would not be needed anyway—the costs of those activities and of the operation of the entire system are reduced. In general, highly specialized, repetitive activities tend to be most appropriate for reliable systems because they are predictable. Finally, since reliability is generally desirable, it is also optimal if it is easy or cheap to build into a system or in systems where bulk and weight are not important.

Maintainability is the optimal design alternative for systems that are needed on unpredictable schedules. It is especially suitable if the unpredictability is accompanied by a fairly continuous need. Regardless of the schedule, if system failure does not incur a major cost, that is, if there is not great disadvantage in having the system unavailable for a short while, maintainability is more justified than reliability. Systems that are designed to perform a range of applications are also optimally designed to be maintainable. Examples of systems that require some slight alteration to make them functional might include machines which can be used as a drill, sander, or router, or an arrow that might be used on large game, birds, or fish. Finally, maintainability is also optimal where economy of either construction, size, or weight is important. For that reason, systems that must be very portable tend to be maintainable.

To summarize, maintainable systems are most appropriate for generalized undertakings that have continuous need but unpredictable schedules and generally low failure costs. This type of situation might be represented by the irregular line shown in Figure 1a. Reliability, on the other hand, is more important where failure cost is high so that the system absolutely must work when it is needed. The highly peaked line in Figure 1b could represent this type of situation. Even where failure cost is not high, systems that have predictable schedules of need interspersed with downtime—like the line shown in Figure 1c—will also be optimally designed to be reliable.

ETHNOGRAPHIC EXAMPLES OF MAINTAINABLE AND RELIABLE WEAPONS

One way to test the utility of these ideas for the interpretation of archaeological remains is to determine if ethnographic hunters make use of both maintainable and reliable weapons systems in situations for which they would be appropriate. In that case, hunters going after game that is continually available but on an unpredictable schedule would optimally be equipped with maintainable weapons. Binford (1980:5) describes such game as "scattered but ubiquitous" and says that it is hunted with a "forager approach." In the converse situation, so-called "collectors" (Binford 1980:10) or hunters who use an "encounter strategy" (Binford 1978b:85) either to focus on specific large game or to take seasonally abundant game, follow a schedule that has predictable periods of need and downtime. They would, thus, optimally use reliable weapons.

The !Kung San are perhaps the best studied and reported hunters who use a foraging strategy. Lee (1979:135) presents a clear and concise description of their weapons kit.

> The complete hunting kit consisting of bow, quiver, and spear, is carried over the left shoulder in a standardized bundle. The spear tip is wedged into the bottom cap of the quiver, and the bow is intertwined with the quiver's shoulder strap. The whole assembly weighs only a few kilograms and it accompanies a !Kung man wherever he goes. Not only on hunting trips but also on visits to other camps, gathering trips, and group moves, the !Kung hunter has to be prepared to hunt on a moment's notice if game is sighted. The contents of a man's quiver include 10 to 15 finished arrows, and a number of blank unfinished main shafts. Perhaps four or five of a man's arrows are fully poisoned and ready to shoot on a given day; an equal number of additional arrows could be made operational with another hour's work. Spare arrowheads and link shafts are often carried in a smaller container made from the tip of the horn of a gemsbok. So the quiver set is a portable workshop as well as a hunting weapon.

Clearly, this kit has many characteristics of a maintainable system. It is light and entirely portable so that it can be carried at all times. It is also markedly generalized in that it is used at all times in much the same form. It does not change from season to season or for different kinds of game. The kit itself includes only a few operative arrows, but these are supplemented by a special set of tools and spare parts the hunter (i.e., the "operator") might need to make unscheduled repairs or adjustments. Finally, the kit includes very few parallel systems. The only attack weapons are a few poisoned arrows. The spear is intended to be used only to dispatch animals weakened by poison.

Amazonian hunters like the Yanomamo also use a foraging approach to hunting and, like the San, they equip themselves with maintainable weapons.

> Just as for all other Yanomamo sub-groups, the basic hunting weapon of the Sanuma of the upper Auaris region is the bow and arrow. Bows are of palm wood, of simple bow form, some 6′6″ in length. The arrows can be as much as 7′9″ in length, the shaft made of a smooth cane which occurs both wild and semi-domesticated. Five different kinds of arrow-heads are used, though three of these are only fixed to the arrow when the right occasions for their use presents itself. Generally, the large lanceolate arrow-head (for shooting terrestrial quadrupeds) and the bone-tipped, barbed arrow-head (for shooting birds) stay fixed in place on the arrows. A man carries three or four, occasionally five, arrows, the typical complement being one with lanceolate and two with barbed arrow-heads. Bow and arrows are carried, held in a single bundle in one hand, above the shoulder much as a javelin-thrower carries the javelin before winding up to throw. In this position, with the forward end of the bundle of arrows and bow almost directly in front of the man's eyes the negotiation of the many obstacles of even a well-used path is least difficult.
>
> A fully equipped hunter also carries a short, 12″ arrow-head case or "quiver". This is made of a section of bamboo and carried on the back with its supporting cord simply looped around the man's neck. The main purpose of these "quivers" is to carry a supply of the "poisoned" arrow-heads used to shoot certain arboreal game animals. Also carried in the "quiver" is always a supply of spare lanceolate arrow-heads. The fifth kind of arrow-head, with a multipronged end, is never carried ready-made, but always improvised on the spot when needed [Taylor 1974:20–21].

Hames (1979:225) adds:

> While hunting, a Yanomamo commonly carries three arrows armed with the three main types of points. Around his neck he suspends a bamboo quiver filled with a dozen or more spare arrow points, thread, latex, and agoouti-tooth tools. Since nearly every time an arrow is fired, at least the point is damaged, an archer uses this tool kit and spare parts to sharpen dull points, replace broken points, or repair broken arrow shafts.

The Yanomamo weapons kit is made to be easily carried. It includes some specialized elements—the arrow points—but these are made as interchangeable modules to be used as parts of the larger system. This kit has essentially no parallel systems. If the first arrow misses the mark, it must be retrieved or another must be retipped before a second shot can be taken. The kit carried by Yanomamo hunters includes both ready-to-use spare parts and specialized tools found only in these kits. With these, repairs can be made very quickly (Hames, personal communication 1984). The system is also designed for some partial functioning because the bow shaft can be used as an emergency spear (Hames, personal communication 1984). Otherwise, if a spear is needed to dispatch an animal, it is improvised on the spot and discarded after use (Taylor 1973:23). With such a kit the Yanomamo hunter can deal with any game he might encounter.

Ethnographic examples of reliable weapons systems are somewhat harder to describe than the maintainable kits treated so far, because they tend to be both larger and more complicated. The

Nunamiut hunters described by Binford (1977, 1978a, 1978b, 1979, 1980) practice an extreme form of encounter hunting with more than 70% of their annual food supply obtained in 30 days of hunting. The major hunting is done during the highly predictable spring and fall caribou migrations. At those times hunters position themselves at places where the animals will be concentrated and focus their entire attention on the repetitive killing of the one species. Transportation technology—both traditionally and today—is effective enough to allow large weapons kits to be brought to the hunting sites. Bulk and weight are, thus, not serious limitations. Obviously, though, success during the hunting periods is critically important. This is a clear situation, in which a highly reliable weapons system would be expected and, indeed, the hunting equipment Binford describes for the Nunamiut has both operational and physical features of a reliable system.

The Nunamiut start preparation of the hunting weapons well in advance of the hunt. In fact, Binford (1978:268) shows that collection of critical raw materials and other "stages" of the tool manufacture are carried on throughout the entire year with an eye toward the hunting season. There is also a specific "gearing up" phase immediately before the hunt begins when tools are put in prime condition before they are needed. Separation between periods of maintenance and use is typical of reliable systems and is carried to the logical conclusion by the Nunamiut who even return exhausted weapons and parts to a base camp before discarding them (Binford 1977:33–34).

The Nunamiut hunting kit has several physical characteristics of a reliable system. Nunamiut tools, like those of other Eskimos, are generally of high quality and good craftsmanship (Binford 1979:267). This assures that they will be strong and serviceable throughout the anticipated period of use. The actual repair kit carried to the hunting site includes a variety of generalized tools—axes and knives—and raw materials necessary to fabricate anything that might be needed (Binford 1977: 25). Besides what is carried, Nunamiut hunters also keep track of large amounts of cached "insurance gear" (Binford 1979:256), which consists of both redundant equipment and resources that can be retrieved and used when needed. Finally, the hunting kit itself includes numerous redundant subsystems. Most noticeably a hunter carries "2 to 4" rifles and an ample supply of ammunition (Binford 1977:25).

In addition to hunters engaged in scheduled encounter hunting like that of the Nunamiut, hunters positioning themselves to take specific quarry that might present itself unexpectedly would also be optimally equipped with reliable systems. Eskimo hunting of seals at breathing holes in winter sea ice is one example of this type of hunting and, as expected, it was carried out with a weapons kit that had many reliable features (see Balikci 1970:67–71; Boas 1968:64–74; Mathiassen 1928:37–44).

Eskimo seal hunters prepared their weapons carefully before setting out on the sea ice, but they did not fully assemble or arm their harpoons until a breathing hole was located and the "hunt" begun. A seal hunter got only one strike so that parallel systems could not easily be built into this hunting kit. Some redundancy was achieved by having groups of hunters work in teams that could blanket a given area and assure success to someone. Ice hunting harpoons were carefully crafted so that they would be strong and true and capable of making maximum advantage of the one opportunity that might be presented. Harpoon foreshafts, which took the major strain, were especially strengthened (i.e., "overdesigned") (Boas 1964:63) and carefully used (i.e., "understressed") (Rasmussen 1931:156) so that they would not break. Also included in the kit were a number of items—like hole probes and seal indicators—that helped the hunter deliver an accurate strike. Harpoon rests were carried to assure that the projectile was conveniently at hand when it was needed. Finally, the ice hunting kit also included a variety of wound plugs and drag lines, which assured that the seal, once struck, could be secured and retrieved. All of this support equipment made the ice hunting system more reliable by helping to assure that the one strike available to the hunter could be as effective as possible.

It is important to note at this point that *not all* Eskimo and arctic hunting systems were designed to be reliable. The weapons kit traditionally used by the Central Eskimo for summer caribou hunting, for example, was strikingly maintainable (see Balikci 1970:39–43; Birket-Smith 1945:49–57; Mathiassen 1928:53–58). This kit consisted of a bow and three or four arrows in various degrees of completeness. These were carried together with a few extra tips and other spare parts (i.e., modules)

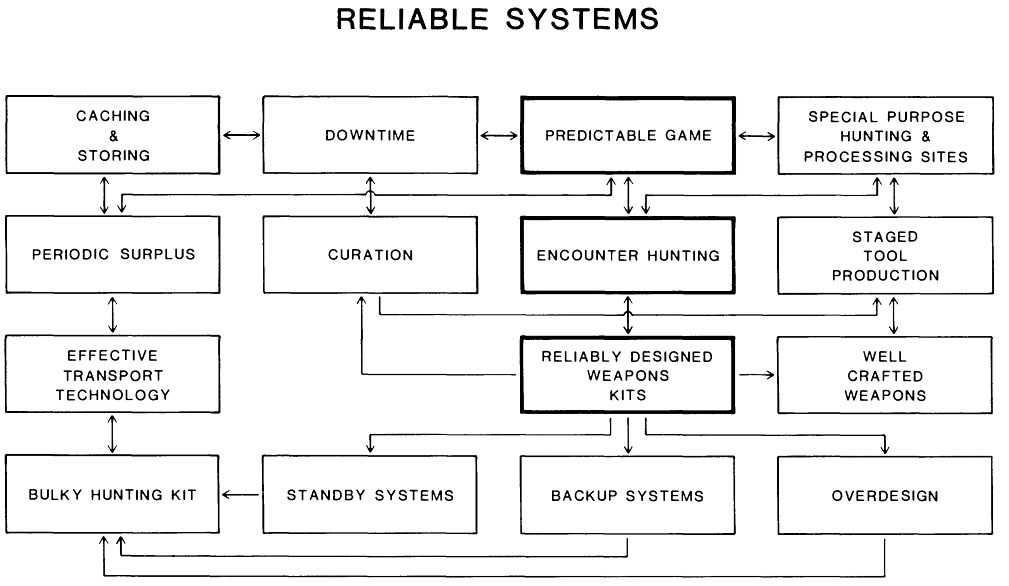

Figure 2. Behavioral, ecological, and archaeological correlates of reliable weapons.

and a small arrow-repair kit in a portable quiver. These weapons were typically used by individual hunters to "take advantage of spontaneous opportunities" (Balikci 1970:42). Eskimo bird hunting gear was similarly maintainable. These systems show that the markedly reliable designs of some Eskimo hunting systems were neither a simple environmental response nor "cultural" patterns in the sense that some cultures simply favor reliable designs while others prefer maintainability.

Other examples of both reliable and maintainable weapons from all parts of the world could easily be cited to support this conclusion. They would add bulk to this presentation, but they would not add substance to the contention that maintainability and reliability are technological alternatives that archaeologists can assume primitive hunters designed into their weapons to optimize certain resources.

DISCUSSION

Bringing the concepts of maintainability and reliability to the study of primitive weapons systems has several potential benefits. Minimally, the concepts are useful for monitoring differences between different weapon assemblages. This is because they do not merely describe the differences between weapons kits, but link them to environmental constraints. As such, these concepts more adequately present the ways in which weapons kits can vary than do most of the other ideas anthropologists have used for that purpose. In that way, these concepts can increase the power of archaeologists to draw inferences from the archaeological record.

Several recent attempts to approach technology in theoretical terms (Oswalt 1979:79–103: Torrence 1983; Zvelebil 1984) have tried to make systematic distinctions between "simple" and "complex" or "specialized" hunting weapons. Such distinctions are less satisfying than the concepts of maintainability and reliability for a variety of reasons. First, as the Eskimo example shows, since individual cultures may support both "simple" and "complex" technologies, these categories are not very neat. In any case, the weapons of "simple" technologies are themselves often as complex as those of the specialized category. Increasing the number of arrows in a quiver or using modular components does not make one more "complex" than another, although such changes clearly do alter the availability of the total weapons system. Finally, and most importantly, the differences between maintainable systems and those designed to be reliable are not simply a result of greater

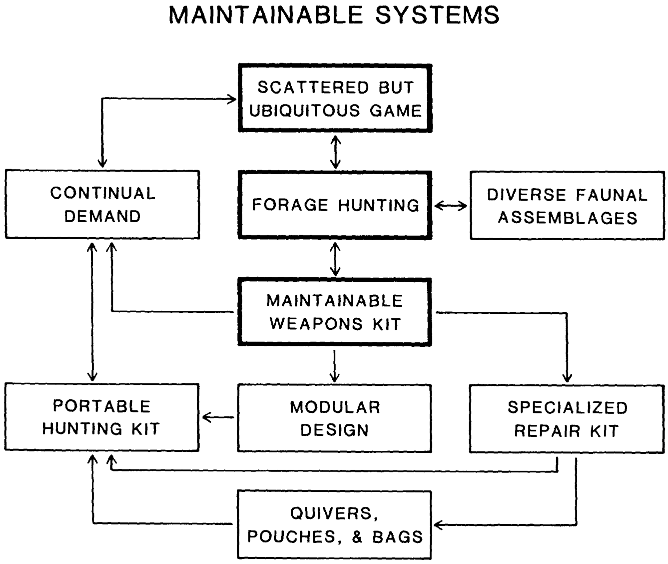

Figure 3. Behavioral, ecological, and archaeological correlates of maintainable weapons.

specialization. They, in fact, reflect basically different hunting patterns and different systemic relationships between hunters and quarry. The design concepts help to explain how and why "complex" weapons can save time or in other ways be beneficial to some hunters. They also give meaning to patterns of caching and tool curation that Binford (1979) has observed to be important parts of some primitive hunting systems.

The most important theoretical utility to be gained by considering the design characteristics of weapons systems is the ability to view technological systems as specific variables that can be altered to reach optimal solutions to environmental problems. Concepts of maintainability and reliability allow analysts to determine the factors that weapons designers chose to optimize and, with that information, to reconstruct both the nature of the animals they were hunting and the strategies they were using to take them.

In Figures 2 and 3 behavioral, ecological, and archaeological correlates of the maintainable and reliable design alternatives are summarized. Reliably designed weapons kits (Figure 2) are part of a complex technological adjustment to game resources that are either fleeting or unpredictably presented. The archaeologically visible manifestations of that adjustment include not only the direct characteristics of reliable design—overdesign, backup and parallel systems, etc.—but also evidence of caching, storage, curation, and special-purpose sites. Correlates such as effective transportation technology and long periods of "downtime" may be less apparent archaeologically but are inferrable in these situations.

Maintainable weapons (Figure 3) designed for "forage hunting" of irregularly available game, will appear archaeologically through their smaller size and modular characteristics. Regular specialized non-weapon tool kits should also be associated with these weapons. This entire kit will occur with a range of faunal remains in markedly general sites.

Because hunting is a complex behavior, it can be studied by means of a wide variety of information sources including site/settlement information and faunal assemblages (see Binford 1977, 1978a, 1978b, 1979). The design concepts discussed in this paper can supplement other records by making weapons themselves a source of information about basic features of primitive hunting strategies. Because weapons are among the most common of all archaeological materials and are more directly approachable than information on topics like regional settlement patterns, design concepts have great potential utility.

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