Carrying demands much, even on flat ground if that ground is soft; then you are forever pulling the cart up and out of its ruts. Knobby tires help a wheel "float" better in soft soil, but beach sand as well as friable garden soil can make transportation difficult with any kind of wheel.

A wheelbarrow is more quickly mired because you are pushing it into the ground. In Figure 9 draw a line from the point where the hand grasps the vehicle through the center of the wheel. For the wheelbarrow the line plows into the ground—your push goes down, making it more difficult to go over obstacles. The line rises with a pulled handcart.

In steep slopes on mucky ground, the arms are hard pressed to tug away at the cart. Pulling forward (which is far more powerful than pushing), the arms tend to pull the body over backwards, and do not successfully link the body's center of gravity with the forces coming from the load. Assistance comes from simple harnesses, which have been used by many handcarters round the world to poise the load over the center of gravity. Once you have tried a harness, you will be amazed at the increase in efficiency and comfort which it affords; it makes a monumental task such as hauling a winter's supply of firewood into an enjoyable one. Their construction and use are described in the accessories section.

THE BASIC BY HAND & FOOT CART

Frame of Steel

Carts and wagons have traditionally had an integrated frame to which are attached the wheels-and-axle and the body. If the body wears out, the structural integrity of the entire cart is not threatened. Rather, the worn piece is replaced. The design used by most modern cart designs is much simpler and more flimsy: the plywood is at once the body and frame.

To understand how this frame works requires a study of the plan drawings and details in Figures 10, 11, and 12, and all the photographs. The purposes of the structural members, named for the analogous pieces made by the British cartwright, are as follows.

The *standard* or *crutch* (see I on Materials List) is traditional in carts and wagons, and is often quite ornate. It supports the cart sides when gates are available at both ends of the cart body. Though missing in most modern garden carts, the standard is extremely important for preventing the sides from bowing out.

One of our tests was to haul a fifty-five-gallon drum half full of sand. Since the drum did not fit into the cart, it exerted terrific pressure against the sides. Yet they held. The best test, however, is moving green firewood, load after load. Modern carts, which have gates but no standards, flunk these tests.

The *bolster* (H) is a support for the standard, a fender for the tire, a step for children getting in and out, and a seat for the *trailer hitch*. The outer edges of the bolster should be ground round since it is a frequently encountered part of the cart. When I first started working with this design, I wrapped the ends of the bolster in cardboard to save my shins; I was accustomed to other carts which do not stick out as far. I have since gotten used to the bolster and appreciate what it does.

The *spar* (C) and *spar brace* (C1) are one unit, but the spar brace does most of the work. The four spars from behind each panel may be omitted since they do not provide much additional strength. The *soles* (D), analagous to the spars but in the bottom of the cart, should not be omitted: they provide necessary support for the floor.

The *struts* (J) are welded to the bottom rail just forward of the *sole brace* (D1) above the *axle* (M), and to the *gate stop* (F) at the front of the cart. The distance from the bottom rail to the ground is thirteen inches. You may prefer to have the struts shaped at a metalworking shop. If the struts are not perfectly matched, the cart will wobble a bit, but it is very difficult to weld so that all four points, two tires and two struts, touch at the same time. Besides, the earth is seldom perfectly flat. Minor wobbles disappear when the cart is loaded.

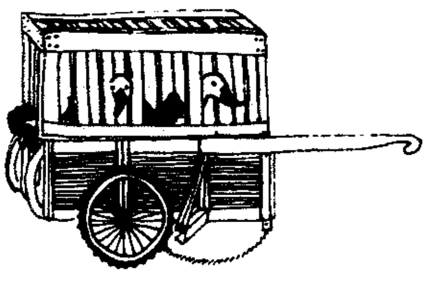
The struts are the brakes of the cart—to slow down or stop, push down on the *shafts* (S) to scrape the struts along the ground. They should be of sturdy stuff, not flimsy tubular electrical conduit as in many modern carts. Use a 5/8-inch reinforcement bar. These struts do not go across the direction of travel, or they would catch the heels of the carter, as they do in other carts.

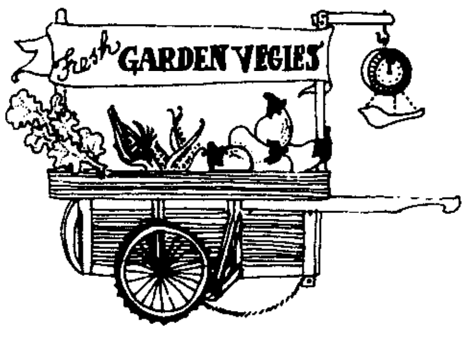
One option is to make the struts removable, by welding threaded studs to the cart, and welding plates with holes in them to the ends of the struts. In this case, the gate stop should be 1 x 2 to give room for a threaded stud. With this

MATERIALS LIST—HANDCART

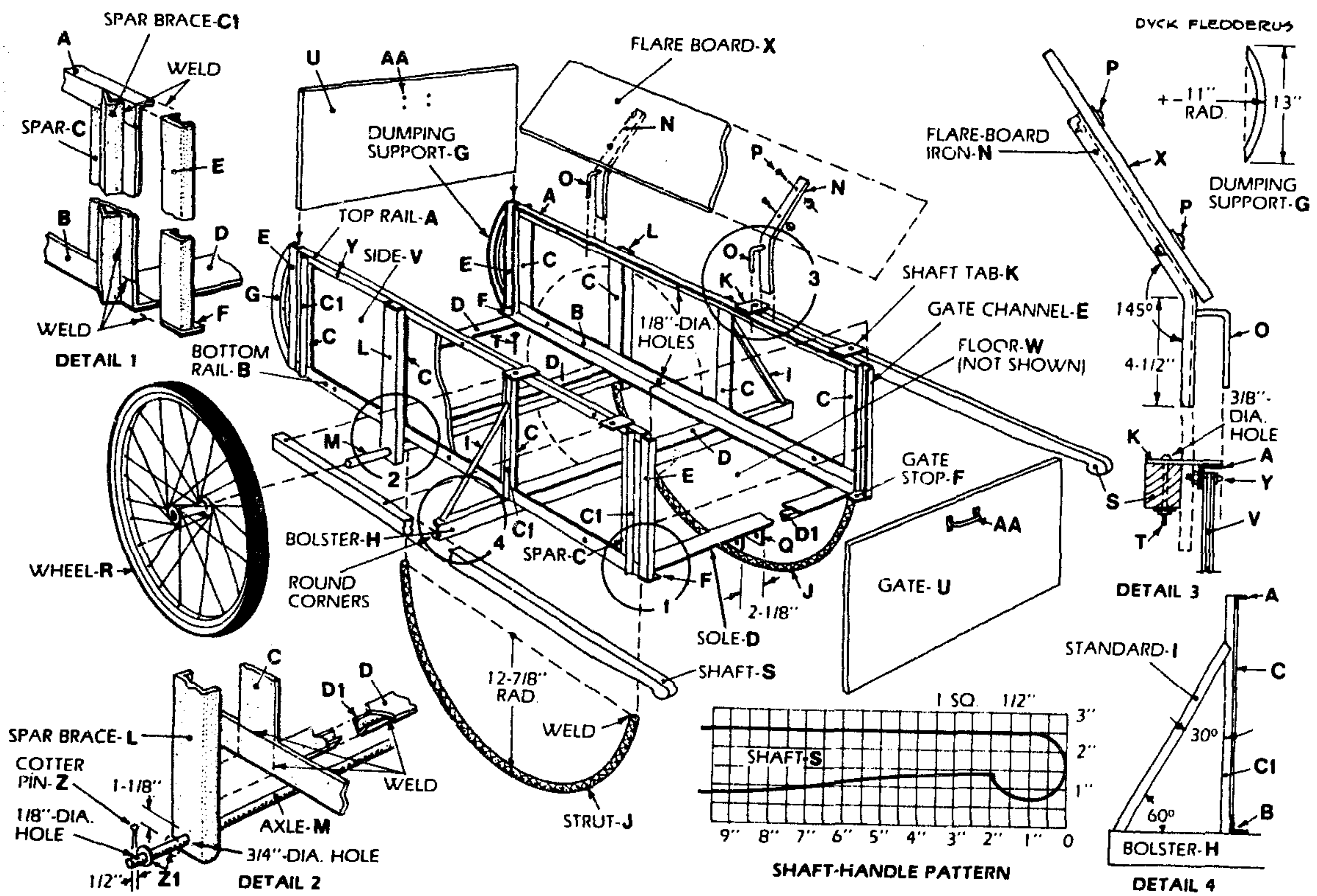
Key	No.	Size and description (use)
A	2	1/8 × 3/4 × 3/4 × 48" steel angle (top rail) *
B	2	1/8 × 5/4 × 5/4 × 48" steel angle (bottom rail) *
C	8	1/8 × 2 × 10 3/4" steel (spar)
C1	6	1/8 × 3/4 × 3/4 × 13" steel angle (spar brace)
D	4	1/8 × 2 × 21 5/8" steel (sole)
D1	3	1/8 × 3/4 × 3/4 × 24" steel angle (sole brace)
E	4	1/8 × 1/2 × 1 × 1/2 × 12 3/4" steel channel (gate channel)
F	4	1/8 × 1 × 1" steel (gate stop)
G	2	1/8 × 3/8 × 1 × 3/8 × 13 3/4" steel channel (dumping support)
H	1	3/16 × 1 × 2 × 1 × 37 1/2" steel channel (bolster)
I	2	1/8 × 3/4 × 3/4 × 13" steel angle (standard)
J	2	5/8"-dia. × 44" steel reinforced (strut)
K	4	3/16 × 2 × 2 1/2" steel (shaft tab)
L	2	1/8 × 1/2 × 1 1/2 × 1/2 × 15 1/4" steel channel (axle spar brace)
M	1	3/4"-dia. × 37" steel rod (axle)
N	4	1/8 × 1/2 × 1 × 1/2 × 13" steel channel (flare board iron)
O	4	1/4 × 1 × 4 1/4" steel (flare board hook)
P	8	5/16"-dia. × 1 1/2" bolts, washers, nuts (for flare boards)
Q	2	3/16 × 2 × 2" steel (trailer hitch tabs, optional)
R	2	26"-dia. × 2.125 spoked wheel and tire with extra-wide spindle
S	2	1 3/8 × 1 3/4 × 48" ash (shafts)
T	4	3/8"-dia. × 2 1/2" bolts, washers, nuts
U	2	1/2 × 12 3/4 × 24" plywood (gates)
V	2	1/2 × 12 × 48" plywood (side panels)
W	1	1/2 × 24 × 48" plywood (floor)
X	2	1/2 × 12 × 48" pine (flare boards)
Y	12	1/8"-dia. × 1" bolts, with washers, nuts (for V)
Z	2	2" cotter pins
Z1	4	1/8 × 3/4"-i.d. × 2"-o.d. washers
AA	2	4" brass handles and eight 1/8"-dia. × 1" bolts with T-nuts

Misc.: Redi-Metal or other acid-cleaning solution, 1 pint metal primer, 1 pint metal paint, paint thinner, exterior enamel, penetrating oil.

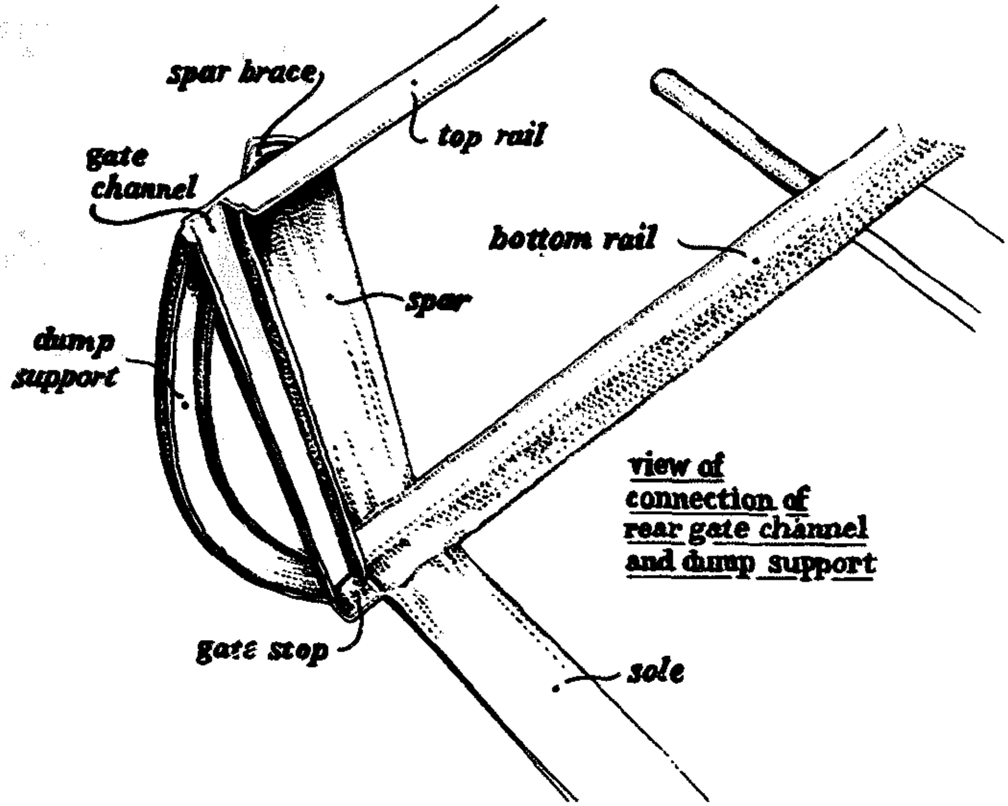




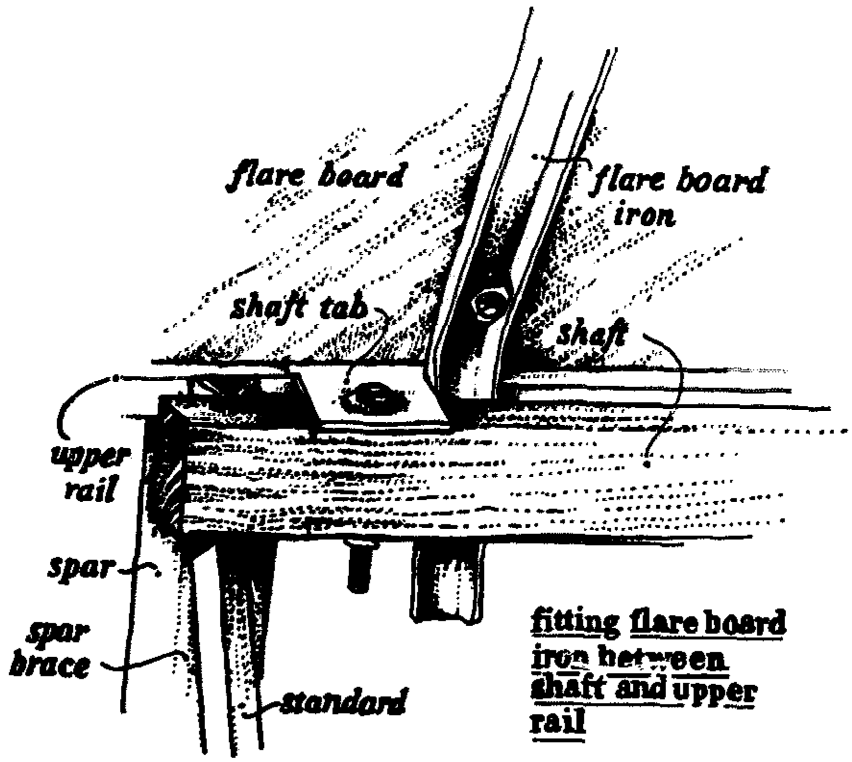
*The 48-inch measurement can also be 47 3/4, as described in the text.



10. The Basic Handcart.



11. View of connection of rear gate channel and dump support.



12. Fitting flare board iron between shaft and upper rail.

modification, the struts can be bolted to the cart or taken off, depending on the use. With a smaller goat for pulling, or with a smaller set of wheels, these struts might be too big.

Dispensing with these struts altogether, a forked stick can be set upright between the ground and one shaft to hold up the cart at rest. Another stick between the ground and the rear of the cart, traditionally called a "dog," would prevent the cart from rolling off its forked-stick strut when the cart is parked.

The *dump supports* (G) permit easier tipping up—for dumping loads, as well as for leaning the cart against a wall to get it out of the way. They keep dirt out of the rear *gate channels* (E). They also serve as handles when the rear of the cart needs to be grasped.

The *trailer hitch tabs* (Q) are not only for small riding mowers. They can be used to attach a goat swingle and a human harness. The tabs must be notched before welding over the front sole brace.

The *wheels* (R) are placed to the rear of center because the most dangerous load is one that is placed too far back, tipping the cart up and maybe hitting someone with the knob of the shafts. The load should be centered just in front of the axle so most of the weight is borne by the wheels but the cart rests firmly on the struts. When going up hills, the load should be even more forward. With the wheels placed to the rear, this cart feels heavier when empty than when loaded. with a load of hundreds of pounds balanced over the axle, the shaft can be lifted with one finger.

Does the frame need to be made of metal? You could make it entirely of wood, mortised and tenoned and pegged, using the principles of bolster and standard, just as the ancient Assyrians did three thousand years ago. They also made their wheels entirely of wood. But few knew then and few know now the skills of the wheelwright and cartwright. Welding, however, is competently done by many; even if one does not do it oneself, one can readily find a welding shop which will purchase or scrounge the metal, cut it, weld it, and grind off the sharp edges. The welded frame has the virtues of strength and ease of repair. If the wood body wears out with use, the frame does not fall apart; new panels can be installed. This frame was tested for seven years against the attacks of young farmhands moving wood, boulders, fenceposts, etc., without bending.

1. Construct a jig to hold the side parts at right angles to the bottom during welding. The jig can be made of 2x4 lumber to a finished size of 12x24x48. It is best to weld the cart upside-down, first the bottom (bottom rails, soles, and sole braces), then each side (spars, spar braces, and top rail). When finished, all excess spatter should be tapped or filed away, and messy welds and sharp corners ground down. Welding is best done with a wire-feed welder since the simpler sorts of welders heat the metal so much that the steel pieces bend when cooling. If an arc welder is used, the top rails should be heavier, say $^3/_{16}$ stock, or as wide as the bottom rails.

2. Holes are drilled:

a.) in the end of the axle spar, ¾ inch diameter, centered 1⅛ inches from the bottom end, through which to slide the axle (part L, see detail 2 in Figure 10);

b.) through the center of the width of the shaft tabs (K), ¼-inch in diameter, ⅝ inch in from the outside edge for the two 2¼-inch bolts (T) which hold the shafts in place (see detail 3);

c.) in the center of the trailer hitch tabs (Q), ½-inch in diameter, for the pin which holds the trailer hitch,

d.) ½ inch from each end of the axle, ⅛-inch in diameter, for the two-inch linch pins (Z), which hold the wheels onto the axle,

e.) in the center of the bolster, ½-inch in diameter, for the trailer hitch locator pin, three places along the side of each top rail

f.) and three places along the side of each bottom rail, ⅛-inch in diameter for the bolts (Y) which hold the side panels in place.

3. The wheels slide on the axle and are held in place by one or more large washers (¾ inch inside

diameter, ¼ inch thick, 2 inches outside diameter).The washers (Z1) are held by cotter or linch pins (Z) set through the end of the axle.

4. Protecting the metal is best done in three steps. First, clean off the rust and dirt, and etch the metal with an acid solution such as "Metalprep", or "Chem-grip", or "Redi-metal" (available from automobile parts stores). Use of these chemicals requires extreme caution (including perhaps a fume mask), but is necessary to ensure a good bond of the paint to the steel. Second, prime the metal to protect it. Third, paint with at least two coats to protect the primer and give the desired color. The "Rustoleum" paint system is a good one. You can expect to use about a pint of primer and a pint of paint, plus thinner. The integrity of the paint coating should be checked once a year. If a patch of rust shows through, the area should be sanded and repainted.

Body of Wood

High quality exterior grade half-inch plywood is strong enough because of the support given by the spars and soles. I have also made a beautiful cart body from hardwood of my own cutting, in tongue-and-groove boards, varnished to show the grain. A friend has lined a By Hand & Foot cart with squared pine boards, which also works very well and is in fact less expensive than plywood or hardwood. Of course, these options require more bolts through the wood into the soles and spars. Gates made of several pieces require support pieces perpendicular to the joints.

Beautiful as my hardwood body is, I think painted plywood is more practical. Bright colors and contrast between the body and the frame are traditional to country and city carts. Indeed, vendors' carts were often carefully painted with thin stripes just in from the edges, as well as the name of the owner (and, occasionally, of the cartwright) in beautiful lettering. Few people realize that the colors of the United States flag came from the vermillion frame, deep blue panels, and bleached white cloth cover of the Conestoga wagons used before the Revolution.

Large clips can also be attached to the outside of the panels or to the underside of the floor for attaching much used implements for which one does not want to rummage around inside the body of the cart. Handcarts in the Army had an ax, shovel, and mattock clipped to the outside; the Army carts had rings, handles, and clips all over the outer surfaces of the cart. Carts made without struts had the forked-stick strut and "dog" ready in this location: One end of the strut was hinged to the edge of the cart, and the free end clipped up underneath, ready to be dropped down to the ground for parking. When pulling a long ladder or a load of fence posts, both gates will be taken out; the gates themselves could have places for storage somewhere on the cart. I store mine underneath, tucked into the channel of the bolster. Each use of the cart has its companion tools which require easy access on the outside of the cart body.

1. For half-inch plywood, the floor (W) is 24 inches by 48 inches notched at four corners to fit around the gates channels. The two side panels (V) are 12 inches by 47¾ inches. the gates (U) should be 12¾ inches by 24 inches, but are cut to fit the gate channels after the frame is made, in case of warpage of the frame during welding.

2. Measure the cart carefully before cutting the wood. Holes or gaps in the wood are then filled, and the panels, floor, and gates are painted with two or more coats of an exterior-grade enamel.

3. After the pieces are cut and painted, lay the floor into place and press the two side panels down so they hold the floor without bolts. Bolt each panel in three places through the top rail and three places through the bottom rail (one-inch bolts, ¼ or 3/16 inches in diameter, with washers at the heads against the wood, and nuts tight against the frame).

4. Finally, attach the two brass handles (AA) to the cart's gates, preferrably with protection for the end of the bolt protruding through the wood (as with a "Pal-nut" or "T-nut").

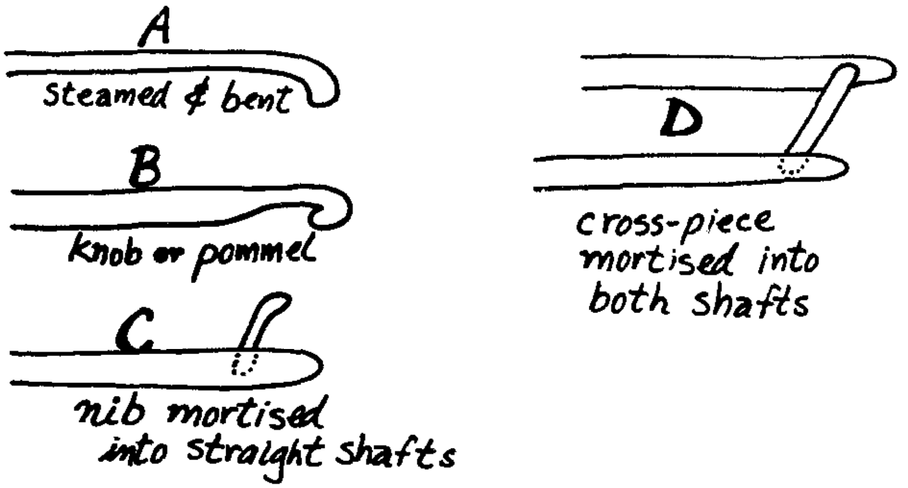
Shafts

The power of the human body must be connected to the cart in as efficient a way as possible.

It is more efficient to pull with shafts than to push a cart. The exceptions are vendors' carts in crowded city streets—these are pushed so that the vendors can keep an eye on their produce. When I lift and push from behind, I also push down, appropriate with a wheel hoe that digs into the ground but not with a load of heavy things. A better use of my power is to lift and pull the cart over obstacles.

Why shafts? The body's center of gravity and power is between the hip-joints. Depending on whether one is speeding up or slowing down, the center of gravity is placed before or behind the place where the hands grip the shafts. If you add turning and tipping, the body must be given great flexibility, much more than that permitted by the small hoops of tubing that most carts provide for handles. To walk outside such a hoop is to walk crookedly, with one's effort mismatched with one's center of power. The weight should be borne from the shafts up through straight arms and down through a straight spine to the center of power. This center will be most of the time exactly between the handgrips. Note that some early handcarts had cross-pieces connecting the shafts, so they ended up looking like the modern hooped carts (Figure 7). The difference is that there was ample room to step inside the hoop, thus fulfilling the need for shafts.

Of the several types of shaft used in other times and places (Figure 13), I prefer style B. Style A is difficult to make and is prone to warping. Styles C and D require careful fitting of the mortise to the tenon, and are more vulnerable to abuse. Style D appears similar to that of many modern carts, but traditionally this style set the cross-piece at least two feet from the cart so the carter could get inside, between the shafts.



13. Styles of shaft.

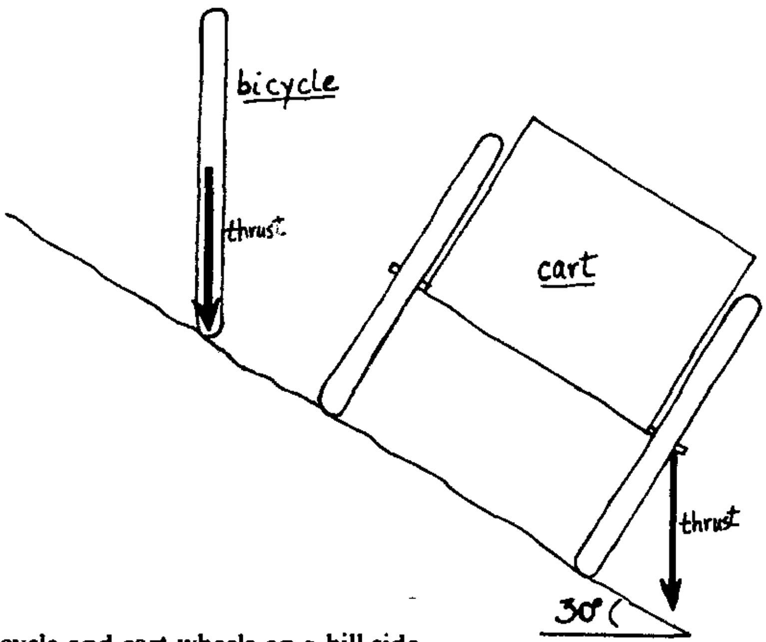
1. Make the knob-end shaft (S) of a straight piece of ash, 48 inches long, $1\frac{3}{8}$ inches wide, and $1\frac{3}{4}$ inches deep. The knob is rough cut with a handsaw, and the inside corner finished with rasps, files, and sandpaper. The knob approximates a 2-inch sphere, and the tapered cut is 7 inches long (see detail in Figure 10). It is bolted up under the shaft tabs, and rests firmly against the front two spar braces. This leaves just the right distance between shaft and top rail for the flare board irons (N).
2. A new shaft can be oiled with a light penetrating oil. Through use the knob and front end will gain a finish from the oils of the hand, but the area around the shaft tabs should probably be oiled once a year.

Wheels

The technological marvel which makes a light and sturdy cart widely available is the modern spoked wheel with a pneumatic tire. Wooden wheels are difficult to make, and quite heavy. All-metal wheels usually have a simple bushing and grease fitting over a solid axle which must be cleaned and greased regularly, are somewhat more difficult to turn, and make a bumpier ride. The pneumatic tire, however, is extremely helpful for smoothing bumps and therefore the task of the cart and carter.

The diameter of the wheel has been traditionally between 24 and 48 inches, the larger diameter necessary when the bearings are crude and resisting. Small diameter wheels, even with good bearings and pneumatic tires, do not smooth bumps adequately, they become enmired in soft ground easily, they cause the carter to bend over backwards to move it, and they cause the load to be tilted when underway. Small wheels are fine on hard, smooth, and level cement, as with a "handtruck" or "dolly" in a warehouse, but not for the diverse conditions for which one needs a handcart.

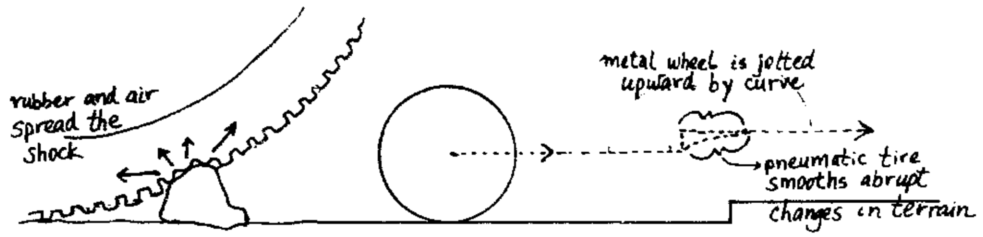
Most of the recent build-it-yourself plans for two-wheel handcarts are built around used bicycle wheels. I do not recommend this since bicycle wheels are made to carry not much over a hundred pounds each in a vertical position. Wheels on bicycles are always vertical in relationship to the forces acting on them, even across a hillside. The force of the load in a two-wheel cart across a hillside, however, pushes across the wheel (Figure 15). A cart wheel must be wider, with thicker spokes, and more strongly made all around.



15. Bicycle and cart wheels on a hill side.

The wheel that I prefer is large (26 inches diameter), wide (2.125 inches wide), with thick spokes (.156 inch vs. .080 found in most bicycles) welded to the hub and rim, with heavy tread tire, with inner tube, and with two sealed ball bearing units per wheel. These wheels have been tested by mounting on a cart faced across the side of a hill with a slope of thirty degrees (Figure 15). At 750 pounds, the spokes of the lower wheel began to bow seriously. Much more stress and they would have collapsed, as I have observed bicycle wheels on carts to do. Note that some of the requirements for bicycle wheels, e.g., precise roundness and trueness, are not problems for low-speed applications as in handcarts.

Heavy tread pneumatic tires smooth out the ride for cart, load, and carter by flexing around small bumps and obstacles (Figure 14). The tires should be inflated to at least 30 pounds per square inch (psi), and as high as 50 psi, but the best guide is the shape of the tire when the cart is loaded. When the tire is flattened, the friction will be greater and pulling more difficult. When the tire is rigid, it is easier to turn but it is also readier to burst if it travels over a sharp rock, though we have had no trouble with this in years of work on carts. A slightly depressed tire under a large load indicates the pressure is just right.



14. Pneumatic tire smoothing bumps.

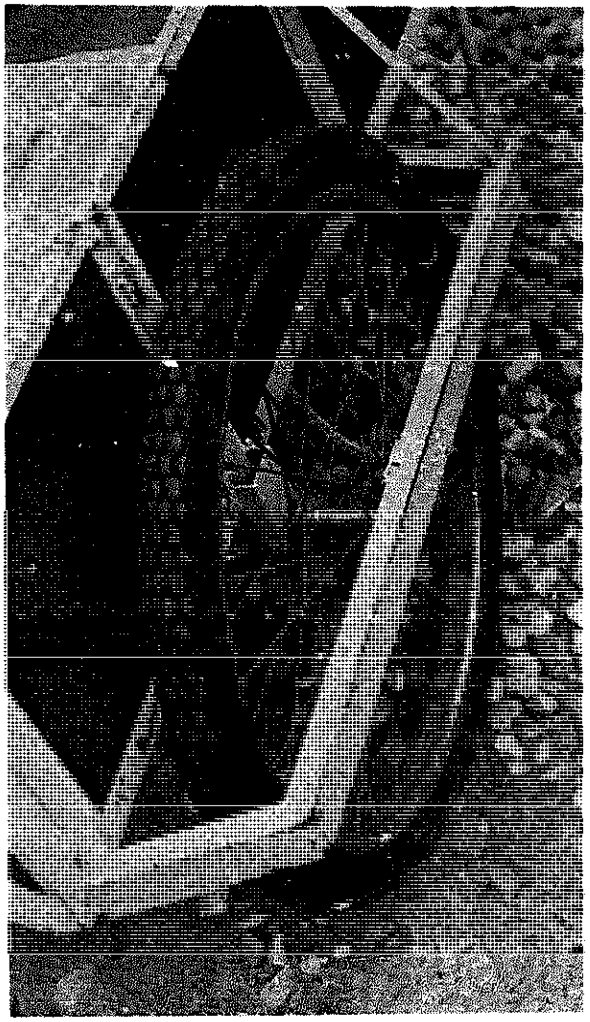
Every six months or so the cart should be turned over and the wheels spun. There should not be much play from side to side, indicating worn bearings. The wheels should spin free for at least thirty seconds. If there is resistance or a gritty feel to the bearings, then the bearings should be replaced. Although they are sealed, dirt can find a way inside and quickly scars the balls or the bearing race. To replace the bearing units, knock them out with a long thin chisel or old screwdriver inserted through the hub. The new units should be tapped into place only around the edge; if you hammer on the center of the bearing unit, that is, the part that moves with the axle, you may distort the bearing race or damage the balls.

The nickel- or chrome-plated spokes and rim can be painted to match the metal of the frame. Another option is to paint the tires with black tire paint, used by many fire stations to make their firetrucks more attractive.

Bicycle Wheels

If you insist on using bicycle wheels, I recommend using wheels twenty-six inches in diameter with as wide a spindle as can be found. I also recommend changing the spokes to a large diameter (at least to .105 inches, a readily available spoke size). Spokes can be obtained through a local bike shop and the procedure is carefully explained in *Building Bicycle Wheels* by Robert Wright (from Anderson World, Inc., P.O.B. 159, Mountain View, CA) and in *The Bicycle Wheel* by Jobst Brandt (Avocet, Inc., Menlo Park, CA). I believe that a home-made highly tensioned wheel may match the strength of the welded spoke wheels described above.

Since bicycle wheels are usually supported on both sides of the hub, the frame needs to be constructed differently. A second bolster, of the same size as the first, must replace the rear sole brace. Two sections of channel, which we shall call the fenders, must be welded between the ends of the first and second bolsters. To these fenders a plate should be welded with a slot in it directly across from the axle spar, which is drilled with a smaller hole. I have not given dimensions because bicycle wheels vary so much but I include Figure 16 to give the general idea. For a typical bicycle wheel (26 x 1⅜), a plate $\frac{3}{16}$-inch thick, and 2 inches by 2 inches, should be welded to the fender. There should be 3⅜ inches between this plate and the axle spar. The hole in the axle spar, and the width of the slot in the plate directly across from it, should be ½ inch in diameter.



16. Adapting the frame to a bicycle wheel.

In my experience, bicycle wheels used on carts, not designed for the many shear forces put across the wheels, must be serviced fairly often. The spokes must be kept tight. The bearings and bearing race must be cleaned and repacked regularly, especially since replacement is so expensive.

Remodeling a Garden Way-style cart

In my experience, the popular Garden Way-style carts (made by Garden Way in Charlotte, VT or by any of the many imitators of this style) have several serious design problems. From my research on the historical uses of two-wheel hand-carts, I have found that these problems were solved many years ago by carters who used their vehicles all day every day: They did not tolerate preventable deficiencies. Several of these problems can be solved by retrofitting a Garden Way-style cart, although it will never equal in strength and versatility the modern cart design detailed in this handbook. On the other hand, there are hundreds of thousands of Garden Way-style carts in use, and that is why I offer these plans for improving a tool which many people already have. Even if a Garden Way-style cart can never do all that the sturdier By Hand & Foot cart can do, it can be made to work better and more safely.