Improving animal-based transport: technical aspects of cart design

by

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Abstract

Transport of goods in rural areas in Africa is carried out mainly on foot, imposing a major burden on rural households in terms of both time and effort. Animal-drawn carts can considerably reduce this burden and so improve the productivity of small farmers, but their use is still quite limited. Poor availability and/or high cost of materials and components both constrain production and cause wide variations in the design and quality of construction of carts. One means of improving the quality of carts is to increase awareness of good design practice and of design features that have proved successful in practice. This paper reviews the various issues of cart design and compares some of the available options. It attempts to establish a sound technical base for cart design. The paper concentrates on design of two-wheel carts for oxen and donkeys.

Introduction

Surveys indicate that up to 90% of travel in rural areas involves transportation of goods and that a large portion of this is done by head, back or shoulder carrying. Transport therefore imposes a considerable burden on rural people in both time and effort and limits the efficiency and output of small farmers. For the foreseeable future it seems that the main option for reducing the transport burden will be to increase the use of non-motorised means of transport such as bicycles, handcarts and animal-based transport.

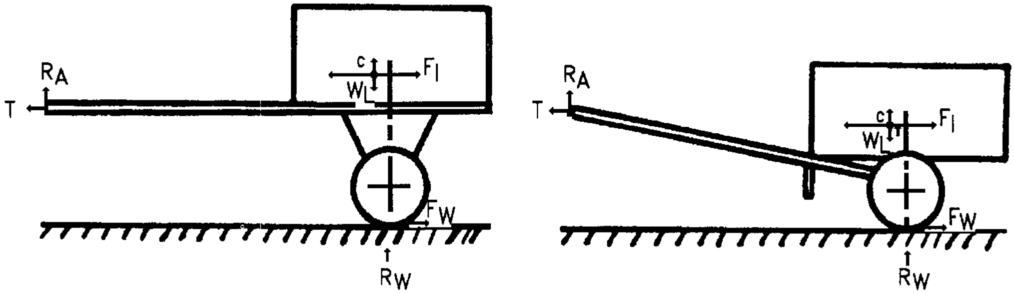
Animal-drawn carts have about 40 times the load carrying capacity of human porterage (see Table 1) and can make an important contribution to improving rural transport. Their use varies greatly from country to country and also regionally within countries. The main reasons limiting wider use of carts are their high cost compared to rural incomes and lack of credit facilities to support their purchase. Technical and cultural factors also impose limitations. The main technical constraint is usually the lack of access to suitable materials or components needed to produce reasonable quality carts, but poor design and/or construction methods may also limit the supply of carts which are acceptable to rural households.

A cart is basically a simple vehicle and in an ideal situation the construction would comprise a welded steel frame, pneumatic-tyred wheels running on roller bearings and a sheet steel or wooden body. However, there will often be constraints on the use of the most suitable materials or components of construction due to high cost and/or lack of availability. Compromise solutions therefore have to be adopted and a fairly wide range of cart designs exists to suit the available and affordable resources in different locations.

The quality and performance of carts varies widely and there is considerable scope for improving the overall standard of design and construction. A first step is to increase the level of awareness of good design practice and of design features which have been proven successful by experience. With this in mind this paper reviews the various aspects of cart design and compares the different design options which are available. It attempts to establish a sound technical base for cart design. Particular attention is given to wheels and axles which have the greatest

Table 1: Comparison of typical loads and speeds of some transport systems

Means of transport	*Load capacity (kg)*	*Typical speed (km/hour)*	*Load carrying capacity (tonne–km/hour)*
Human (headloading)	25	4	0.1
Donkey (pack load)	50	5	0.25
Ox cart	1 000	4	4
Two wheel tractor	1 000	10	10
Tractor/trailer	3 000	20	60
Truck	10 000	50	500



W_L	*total cart weight*	F_W	*resisting force at wheel: sum of rolling resistance and bearing friction*
F_I	*inertia force*	c	*centre of gravity. This should be close to the wheel axis to limit downward forces on the animal and as low as possible for stability*
T	*tractive force*		
R_A	*vertical reaction from animal*		
R_W	*vertical reaction from wheel*		

Figure 1: Basic configurations of animal-drawn carts

effect on cart quality and performance and are also the major problem for small-scale cart producers. The information presented is based on professional experience and tests on wheels and bearings carried out by IT Transport. The paper concentrates on two-wheel carts pulled by oxen and donkeys, as most carts in rural Africa are of this type. The paper briefly reviews all aspects of cart design, but it does not tackle the closely related topic of harnessing.

Basic design factors

Cart capacity

Capacity must be matched against the draft effort available from the animals. It is generally recognised (eg, Goe and McDowell, 1980) that the average draft effort of a pair of oxen is about 9–11% of their combined body weight, ie, a total effort of 90–170 kgf. Allowing an overall resistance factor of 0.1 for wheel resistance, bearing friction and gradient, and an average draft of 130 kgf (1300 N), the limit on total cart weight is about 1300 kg, giving a load capacity of around 1000 kg: most carts are designed for an 800–1000 kg capacity.

The average draft capacity of a donkey is about 15% of its body weight giving a draft effort of 30–50 kgf (300–500 N). On the same assumptions as above, the average total weight of a donkey cart should be about 400 kg for a single donkey or about 700 kg for a pair of donkeys. This should give a cart capacity of 250–300 kg for a single donkey and 500–550 kg for a pair of donkeys.

The load capacities given in Table 1 are for well designed carts operating on reasonably firm surfaces with medium gradients. Animals can exert much higher draft forces for short periods of time, but if carts have to operate continuously on soft or sandy surfaces or on hilly terrain then load capacities will need to be reduced

Overall layout of cart

Carts consist basically of a wheel–axle assembly, a chassis or frame, a load platform or body and a drawpole. The major feature governing layout is the orientation of the drawpole and the resulting height of the cart body. The two basic configurations are illustrated in Figure 1.

A tilted drawpole allows the body of a cart to be lowered by about 40 cm. The resulting lower centre of gravity of the loaded cart is an important benefit to stability, particularly when operating on slopes, and makes the cart easier to load. The rear end of the drawpole may conveniently be attached via a bracket to the axle of the cart.

The other important aspect of layout is the balance of the cart, which affects the vertical load which has to be supported by the animal(s). The load an animal can pull is several times greater than the load it can carry. If the proportion of a cart load that has to supported (“carried”) by the animals is increased, less energy and effort will be available for the more efficient work of pulling the cart. The trend of higher supporting loads reducing overall transport efficiency seems to have been confirmed (see O’Neill, Hayton and Sims, 1989) although it does not yet appear to have been quantified.

An upper limit of vertical load of 20 kg has been suggested (FAO, 1972). This requires that the centre of gravity should be about 7 cm in front of the axle for a typical laden cart in which the distance from axle to hitch point is 300–350 cm. Although farmers are unlikely to have the time or inclination to worry about such precision when loading their carts they should check that the vertical load on the animal(s) is not excessive if they want the animal(s) to work to full capacity.

In India an attempt was made to overcome the problem by placing a third wheel (castor) at the front of the cart to eliminate the load on the animal. However, this increases cost and reduces stability of the cart and it has not caught on.

Choice of wheels

The efficiency and reliability of a cart depend largely on the design and performance of the wheel–axle assembly. The acquisition or construction of this assembly also constitutes the main problem for workshops involved in cart production, and is often a major bottleneck for smaller workshops. The cost of the wheel–axle assembly is likely to constitute between 40 and 70% of the production cost of the cart.. In the following sections, aspects of wheels, tyres, hubs, bearings and axles are discussed, but ideally these components should be considered as part of an integral assembly.

Types of tyres

Pneumatic tyres provide important benefits over rigid tyres in terms of cushioning impacts to give a smoother ride and having a lower rolling resistance for a similar sized wheel. However, they are prone to puncturing which can be a major disadvantage in some situations.

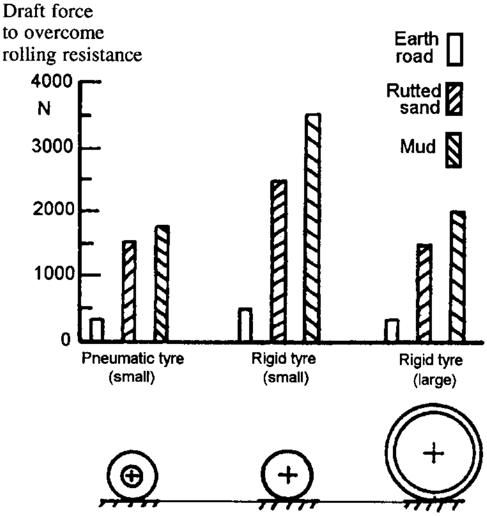


Figure 2: Comparison of rolling resistance on different road types of pneumatic and two sizes of rigid tyres (illustrative information from various sources presented as draft force (in Newtons) needed to overcome rolling resistance for wheel load of 1000 kgf or 10 000 N)

Rigid tyres include rims of steel wheels, steel tyres around wooden wheels and solid-rubber tyres. Their main advantages are that they can be made by small workshops and artisans using locally available materials, they are cheaper to make, and maintenance costs and problems are less than for pneumatic tyres. However, high impact loads from rigid tyres cause discomfort for the towing animal(s), may cause damage to the goods being carried, and generally accelerate wear and tear of cart components so that carts need to be more robust and therefore heavier. A further disadvantage is the damage they may cause to roads.

Figure 2 shows a comparison of the rolling resistance of pneumatic and rigid tyres on a number of surfaces. It is seen that to have the same rolling resistance, rigid tyres should be roughly twice the diameter of pneumatic tyres. Large wheels of this diameter, 1.2–1.5 m, are seldom found in African countries but are standard on carts in Asian countries such as India and Bangladesh. Rigid-tyre wheels on African carts are generally 0.7–0.9 m in diameter, which makes the carts more difficult to pull and reduces load capacity.

Although farmers generally recognise the benefits of pneumatic tyres they may sometimes choose rigid-tyre wheels because of reduced maintenance, especially the absence of punctures, or because of their lower cost and local availability.

The supply and cost of pneumatic tyres may sometimes be problems for cart manufacturers, particularly for smaller workshops. The latter often use scrap tyres which are usually badly worn and therefore very susceptible to puncturing. The specifications for tyres for carts are less demanding than for higher speed vehicles and it is possible that cheaper, lower grade tyres could be produced specifically for carts. Starkey (1989) reports the use of reject tyres in West Africa but there appear to have been few other innovations on this topic. This may be worth further investigation.

Wheels for pneumatic tyres

Car and truck wheels have rolled rims and pressed centres. Their high strength-to-weight ratio is achieved by forming sheet steel into relatively complex profiles which have high structural strength. The expensive equipment needed for this is only economical for high volume production and is generally not suited to non-industrialised countries.

Simpler forms of wheels for pneumatic tyres can be produced locally on less costly equipment, but these need to use thicker material to retain strength and therefore tend to be heavier. For example:

- Camartec in Tanzania has developed a wheel comprising two halves hot-pressed from 3 mm steel sheet which are bolted together with a rolled rim welded in between. This manufacturing method is suited to centralised production of wheels in larger, well equipped workshops. Camartec also produces fabricated split-rim wheels, with rims formed on a rolling machine
- IT Transport has developed a low-cost technology for producing split-rim wheels in which a hand-operated bending machine is used to produce good quality rims (Dennis, 1990). This manufacturing method is suited to small to medium workshops and for production levels of up to 500 wheels a year.

Split-rim wheels are made in two parts which bolt together from either side of the tyre. They therefore have substantial benefits for use on carts as tyres can be easily fitted and removed using only a spanner: the inner part of the wheel can in fact be left mounted on the axle.

Rigid-tyre wheels

Two common types of wooden wheels are produced:

- wooden disc wheels are formed by cutting a disc from a sandwich structure of wooden planks. They are the simplest form of wheel to construct but are heavy and inefficient. However, they are suitable for very basic carts because they can be made by local artisans or farmers from readily available materials using hand tools
- wooden spoked wheels are considerably more complex to make and require good carpentry skills. Spoked wheels were commonly used on carts in many countries in the past and are still widely used in some Asian countries. However, high-grade wood and good wheelwright skills are needed to produce good quality wheels. These are not generally available in African countries and the spoked wheels produced tend to be fairly crude and smaller in diameter than traditional cart wheels so that they do not perform well and have poor appeal for cart buyers.

Wooden wheels should have steel or rubber strip tyres fitted to protect the rims and the wood needs to be adequately protected against adverse environmental conditions. Even so, these wheels are susceptible to distortion and cracking of the wood and from deterioration and loosening of joints under repeated impact loads. However, it seems likely that wood will continue to be used for very low cost disc wheels and in locations where steel is not readily available.

Steel wheels comprise rims formed from flat steel bar, 8–12 mm thick and 70–100 mm wide, joined to a hub by welded-in steel spokes. Rims may be formed by rolling (equipment is not widely available), by bending around a former or by blacksmithing techniques: the latter method requires considerable time and effort and may result in poorer quality rims. A common problem of these wheels is fatigue fracture at the welded joints: for instance, Shetto and Kwiligwa (1988) reported that 50% of the steel wheels in their survey had suffered fatigue failures. The problem could be overcome by a better understanding of the structural design of the wheel: the flat bar rims in particular are heavy and structurally inefficient. Another problem is that when operating on sandy surfaces, the rims tend to pick up sand and deposit it on the hubs, greatly accelerating wear on the bearings.

Steel wheels tend to have more appeal to cart buyers than wooden wheels and are quite widely used, particularly in regions where puncturing of pneumatic tyres is a serious problem. They could be improved by better structural design to reduce weight and failures and by a wider use of simple equipment to produce good quality rims.

Puncture-proof tyres

Because pneumatic tyres offer considerable benefits to cart performance, but punctures are a major source of concern to cart owners and buyers, there could be potential for some form of puncture-proof tyre which offers some degree of cushioning but with a much reduced risk of puncturing. The following are some possibilities which might be considered.

- agricultural tyres with increased tread thickness are much less prone to punctures but are not foolproof. This type of tyre should be considered in any move towards producing special tyres for cart wheels
- the standard method for puncture proofing “off road” vehicle tyres is to fill them with urethane foam. This is 100% effective but is costly and would rely on imported materials so that it is unlikely to be appropriate for cart wheels
- some attempts have been made to fill tyres with sawdust but it is difficult to compact it adequately and ingress of water turns it into a heavy, soggy pulp
- the increased concentration of carts in certain regions may act as an incentive to establish puncture repair workshops. This could be a partial solution but punctures will still result in

considerable "down time" of carts, particularly for farmers working in more remote areas

- various experiments are being carried out on the use of non-inflated rubber tyres which are stiffened by mechanical means. The Technology Development and Advisory Unit (TDAU) of the University of Zambia has patented the "flexiwheel", which uses sections of scrap tyres mechanically supported or bolted in place around a wooden disc. Early results are encouraging, but the wheels are very heavy—75 kg for one wheel (Vroom, 1994).

Puncture proofing is an area where further development and testing are required.

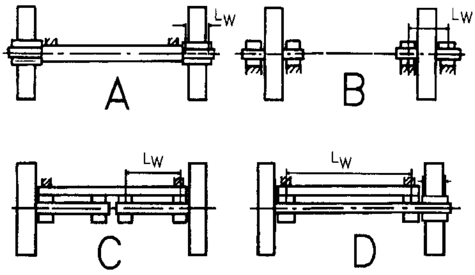
Bearings

The basic principles and arrangements for supporting axles are illustrated in Figure 3. The bearings have to support both vertical and side loads from the wheel. Side loads from cornering will be quite small on carts but those from impacts against potholes, ridges, rocks, etc, may be up to 15% of vertical loads (Dennis, 1990). They exert a leverage effect on the wheel which increases with wheel size and to combat this the effective length of the bearing should be as large as possible. This has an added advantage in reducing the freedom of the wheel to "wobble". In bush bearings, side loads tend to concentrate wear at the ends of the bearings leading to increased wheel wobble which aggravates the problem, the combined effect leading to accelerated wear of the bush.

Rolling contact (ball and roller) bearings

Rolling contact bearings provide smooth precision running with negligible friction and wear, high reliability and low maintenance, provided they are properly mounted, lubricated and protected against ingress of sand and dirt. However, they must be imported, and are therefore relatively costly and not always readily available. Also, if imported bearings are fitted to locally-made hubs and axle, these must be accurately machined, necessitating access to a lathe.

The bearings most commonly used on carts come from scrap hub assemblies from motor vehicles. These may give problems if they are approaching the end of their operating life and finding replacement bearings of the same type may be very difficult. Some better equipped workshops also produce machined hubs incorporating imported bearings. This seems to be a viable approach which should be developed as it could allow standardisation on a few sizes of bearings, hopefully leading to reduced costs and improved availability.



Lw effective bearing length (length resisting side load and wheel wobble)

A wheels rotating on stub axles attached to an axle beam. This is the simplest and most common arrangement

B two live axles rotating in bearing blocks located either side of the wheels. This requires a more extensive cart frame and is seldom used

C two live axles rotating in bearing blocks attached to an axle beam. This has significant advantages in minimising the effects of wear (the bearing wear and resulting wheel wobble may be only about 10% of that for the bush arrangement A). However, the bearings are more difficult to align and bearing friction may be greater

D a single live axle with one wheel fixed to the axle and the other free to rotate. The latter wheel only rotates on the axle when the cart is not moving in a straight line so wear in the bushes should be substantially reduced. This arrangement has some advantages over C: although it has been suggested for use on carts it is not known if it has actually been tested

Figure 3: Basic arrangements of wheel–axle assemblies

Taper-roller and deep-groove ball bearings are the most appropriate types because of their ability to support both radial and axial loads.

Taper-roller bearings have the higher load capacity and are commonly used in hubs of motor vehicle wheels. However, they are fitted in two parts which must be carefully adjusted to give the correct tightness of the bearing. A good degree of skill and care is therefore needed in assembling the hubs.

Deep-groove ball bearings are single piece bearings which require axial location in the hub but not adjustment. They are cheaper than taper-roller bearings and can be obtained sealed and pre-greased for life, which is a useful advantage. Because of the point contacts of the balls the bearings are more susceptible to damage from impact loads, but providing they are adequately sized and spaced apart in the hub they should perform quite satisfactorily.

Locally made rolling contact bearings may offer a satisfactory, intermediate alternative which is cheaper and more readily available than imported

Table 2: Typical values of bearing pressure (P) and "PV" factors for various materials

	P (kg/cm^2)	PV ($x10^4$ kg/m/s)
Bronze	350	14.5
Cast iron	500	11.0
Hardwood	140	3.6
Unfilled nylon	70	1.1

bearings. Roller bearings with unhardened rollers and races have been used on carts in India and are at present being investigated at the Development Technology Unit, University of Warwick, UK (Oram, 1994) and also by IT Transport. They appear quite promising but can only support radial loads so that additional thrust washers are needed. A cup and cone type of ball bearing (similar to a bicycle axle arrangement), using hardened balls and case hardened races, is being developed by Camartec in Tanzania: this supports both radial and axial loads.

Plain bearings

Plain bearings involve sliding contact between the bearing and axle so that both friction and wear are substantially higher than for rolling contact bearings. Their advantages are that they are cheaper and can be made from locally available materials.

The design of these bearings is based on allowable values of bearing pressure, P (kg/cm^2), and "PV" factor, where V (m/s) is the sliding velocity between bearing and axle. Typical values for cart bearings are P = 10 and PV = 1.2. Allowable values for some bearing materials are given in Table 2.

These design data indicate that bronze, cast iron and hardwoods should be satisfactory for cart bearings but plain nylon is very marginal. However, the performance of plain bearings is very much dependent on proper lubrication and the exclusion of abrasive materials, and bearing materials which should be satisfactory may perform very poorly because of inadequate attention to these two factors.

The materials commonly used for plain bearings in industrialised countries are bronze and polymers. A wide range of low-wearing polymers are available but they are relatively costly and would need to be imported for use on carts. Materials which are locally available and have been used on carts include:

- **phosphor bronze**: this is a relatively hard material and it is recommended that axles are case hardened. Bushes need to be machined on a lathe
- **cast iron**: this is cheaper than bronze and does not perform quite so well. Other comments are the same as for bronze
- **mild steel**: mild steel bearings running on steel axles are very prone to seizure and should be avoided. In general, identical or similar pairs of materials should not be used. If steel is to be used then either the bearing, the axle or, preferably, both should be case hardened
- **hardwoods**: these are suitable bearing materials and are still used in some particularly dirty conditions in industrialised countries. Hardwood is best used in the form of oil-soaked bearings and, because of its higher wear rate, in a live axle arrangement which should have a life at least 5 to 10 times longer than wooden bushes used in a hub assembly. Significant advantages are that good quality bearings can be produced without a lathe and that they are cheap and can be readily replaced.

The performance of plain bearings used on cart wheels has been very variable. Dogger (1990) cites bronze bushes which wore out completely in less than one year, while Müller (1986) quotes a case of hardwood bearings in a live axle arrangement lasting more than 12 years. Although different operating conditions may partially account for variations in performance the major factors are undoubtedly attention to lubrication and protection against ingress of sand and dirt. The two main areas for improving performance of plain bearings are therefore:

- improved methods of lubrication, particularly in terms of retaining lubricant in the bearing for longer periods to avoid the need for regular lubrication (which experience shows is rarely carried out)
- improved shielding or sealing of bearings to prevent the ingress of sand and dirt.

Friction and wear in bearings

Data on the friction and wear of common types of bearings are shown in Figure 4: they are obtained partly from the literature and partly from testing carried out by IT Transport.

Friction data are presented in terms of the draft effort needed to overcome bearing friction for a cart with a wheel load of 10 000 N (or 1000 kgf). This is obtained from the expression:

$$Draft\ effort = \frac{f W d}{D}$$

where f is the coefficient of friction, W is load (1000 kgf), d is axle diameter (assumed 50 mm) and D is wheel diameter (assumed 700 mm). The expression indicates that the draft effort needed to overcome bearing friction gets smaller as the wheel diameter increases. Bearing wear may also be smaller because the rotational speed of the wheel will decrease, but this will be counteracted by the increased effect of side loads on the wheel.

Figure 4 shows that the draft effort is:

- negligible for rolling contact bearings
- 100–120 N for lubricated bushes, representing 7–10% of available draft from a pair of oxen
- 150–200 N for lubricated wooden bearings in a live axle assembly or 10–15% of available draft (higher than bush bearings because of increased load at the outer bearing and greater problems in aligning the bearings)
- 300–400 N for unlubricated plain bearings or 25–35% of available draft (note the substantial penalty for inadequate lubrication).

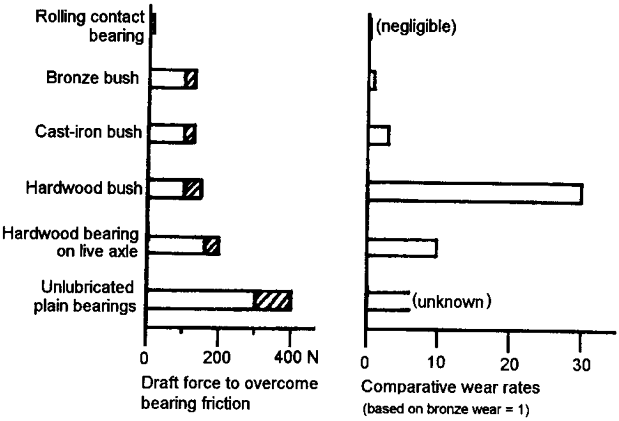


Figure 4: Comparison of friction and wear for various types of bearings. Data are based on draft force required to overcome a bearing load of 10 000 N (or 1000 kgf) and are indicative for good quality bearings, adequately lubricated and sealed against ingress of sand and dirt

Wear of rolling contact bearings is usually negligible (provided abrasive materials are excluded); deterioration tends to be due to surface failures such as pitting. The wear rate for bronze, used as the reference base for plain bearing materials, is roughly equivalent to 1 mm depth of wear of the bush bore in 10 000 hours (but the wear of the axle may be three to four times this value if it is not case hardened). Field experience and preliminary tests by IT Transport suggest that if sand gets into the bearing, wear rates will increase by up to 50 times.

Selection of bearings

The following is a rough order of preference for selecting bearings for best performance and durability:

- commercial rolling contact bearings are the best choice if they are available, affordable and the workshop has access to a lathe
- locally made rolling contact bearings seem promising, but further testing is needed. A lathe is desirable but it may be possible to construct roller bearings from standard sizes of pipe and round bar
- bronze or, more likely, cast iron bushes with case hardened axles. The bushes need to be machined on a lathe
- hardwood bearings used in a live axle arrangement
- other low cost alternatives as they are developed and proven.

In all cases the bearings must be adequately lubricated and sealed or shielded against the ingress of sand and dirt.

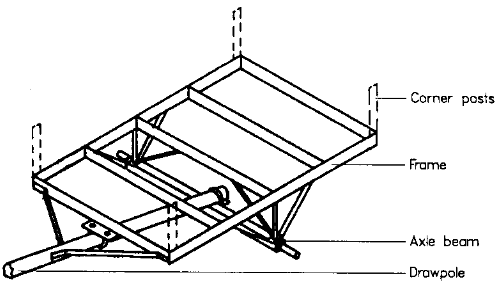
More detailed information on design of bearing/axle assemblies is given by Thoma (1979) and IT (1994).

Frame and body

The size of the cart body should be compatible with its capacity and intended use. Making the body too large is wasteful in terms of increasing the cost and deadweight of the cart, and may encourage overloading. The width is set within limits by the wheelbase which should be standardised at about 1.4 m. Dimensions of ox carts are generally in the range 1.1–1.3 m wide by 1.8–2.2 m long. Donkey carts should be smaller and lighter: for example, a cart for a single donkey might be 1–1.2 m wide and 1.4–1.6 m long.

The cart frame must support the body and transfer the load from the floor area into the axle supports. A typical frame layout is illustrated in Figure 5: it may

Figure 5: Layout of a cart frame



be constructed from steel or wood. A welded steel frame is the most effective design and the simplest to construct, depending on the availability and affordability of suitable steel sections. In construction of wooden frames, care is needed to make joints which effectively lock members together and prevent them from vibrating loose under constant impact loading. The corner uprights may be fitted with brackets to provide for fitting of extension panels for the sides and/or ends of the cart.

Careful attention needs to be given to the design of the body to avoid excess material and weight. Fully enclosing the body can add considerably to its weight. For example, sheet steel bodies commonly used on carts in Zimbabwe weigh roughly 70 kg; a body made from 25 mm thick wooden planks would weigh about 50–60 kg. These represent substantial contributions to the total weight of the cart so careful consideration should be given to the need for a fully enclosed body. Other factors which need to be considered are whether the side and/or rear panels should be removable or hinged to allow easier loading and unloading of the cart, and whether a tipping body is needed. Steel bodies are the more durable, but equipment is needed to cut and fold the sheets: thin sheet material may need folded ribs in the panels to increase rigidity. Wooden planks are widely used for agricultural carts and should be quite adequate, provided appropriate grades of timber are used and properly treated to prevent deterioration from pests and the environment. A wooden body is easier to construct and allows greater flexibility in body design.

Drawpoles may be made of wood or steel pipe. Pipe of the required size is relatively costly so wooden poles are commonly used where they are available. The latter should be attached to the frame with U-bolts: holes should be avoided at the front fixture as they would introduce a point of weakness at the most critical section of the pole. Shetto and Kwiligwa (1988) report that failures of wooden drawpoles are common; 80% of farmers in their survey reported failures, in some cases as many as three a year. Abuse appears to be a common cause for failures, for instance allowing the drawpole to drop to the ground. If this is the case it may be worthwhile considering the addition of legs to the front of the cart which strike the ground just before the drawpole.

In general, carts in rural Africa are too heavy and consideration needs to be given to improving designs by removing excess material. As a comparison, the ox cart produced in Senegal by the Sismar (Siscoma) factory, having a load capacity of 1000 kg, weighs 190 kg, whereas similar capacity carts in Zambia and Zimbabwe often weigh 250–300 kg. It seems that there should be some scope for weight reduction on the latter carts.

Brakes

Carts for use in hilly regions should be provided with adequate braking systems which ensure safe operation. The braking system should control the cart going downhill and, if necessary, hold the cart to allow the animal(s) to rest when going uphill.

Two very simple braking systems are:

- a pole attached to the cart which can be levered to drag against the ground
- animal braking, in which a strap attached to the harness or a crossmember attached to the drawpole restrains the cart against the hind quarters of the animal(s). This is only effective for heavier animals and only works when the cart is going downhill.

These systems are fairly crude and unsatisfactory.

A braking system acting on the wheel or axle would give greater safety. These comprise a friction pad, shoe or band which is forced against the rim of the wheel or against a drum or disc fitted to the wheel or axle (for live axles). To be effective, the friction member should act at as large a radius as possible and have a good area of contact on a surface which is unlikely to get wet. The options include:

- braking against the outside of the tyre. This provides the maximum radius of action but is not very effective in wet conditions and will cause increased wear of pneumatic tyres
- friction pads acting against the inside of the wheel rim, if it is wide enough, or against a drum attached to the wheel or axle. This reduces the radius of action but provides a better braking surface
- a band brake, for example, a leather strap, acting around a drum attached to the wheel or axle.

The simplest form of friction brake comprises a bar, fitted across the cart and free to slide in guides, which has friction pads at each end and is pulled against the wheel or drum by a hand lever. A good lever ratio (eg, 10:1) should be provided and the pulling mechanism should equalise the forces at each end of the braking bar. Pieces cut from scrap tyres may be used as friction pads. A ratchet or stops should be provided to allow the brake lever to be locked on. Further details of braking systems are given by Barwell and Hathway (1986).

Suspension

A suspension is seldom used on carts, or on any farm vehicle. It would be of little use on carts with pneumatic tyres but could provide some benefits for rigid-tyred carts in cushioning impacts and possibly reducing rolling resistance on hard bumpy surfaces. To be effective the suspension must provide good springing involving a reasonable vertical displacement of the body relative to the axle at full load (possibly 20 mm or more). The simplest approach is to use scrap leaf springs from motor vehicles but these are likely to be in short supply. If rubber springs, cut from scrap tyres, are used then some ingenuity will be needed to provide the required vertical springiness at the axle mounting while retaining adequate constraint in the horizontal plane. This is an area in which some development and testing may be justified in conjunction with work on puncture-proof tyres.

Conclusion

This paper has reviewed the design and construction of two-wheel animal-drawn carts. It is clear that the main problem in producing good quality carts, particularly in smaller workshops, is the procurement or construction of suitable wheel–axle assemblies. Scrap axles from motor vehicles are a useful resource but their supply is often too limited to sustain cart production. Secondhand axle assemblies may sometimes be imported but this does not seem a sustainable solution, or in the best interests of developing local capabilities for manufacture and maintenance of carts. A more appropriate approach may be to develop some specialisation in wheel–axle manufacture in certain workshops and to standardise on certain materials and components so that these are more readily available at reasonable costs.

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