CHAPTER 1

INTRODUCTION

Anthropometric measurements are related to the measurements of the Human Body and the Foot Anthropometry specifically relates to the measures of the Human foot (Isman and Inman 1969). This data assumes significance as the foot is one of the major organs of the Human Body and any debilitation in the foot would lead to serious consequences to the person with the foot debility (Agić et al 2006). One of the major causes of foot debilitation is the wearing of ill-fitting and improper footwear which causes blisters, corns and other foot injuries which if left untreated could lead to limb impairment and damage. To avoid such an occurrence it becomes imperative to design and develop proper and correctly fitting footwear and the major ingredient in the success and provision of correctly fitting footwear is the “Last”, which is a three dimensional form of the Foot and on which the footwear would be made (Luximon and Luximon 2009). This lends the correct shape, fitting and dimensions to the footwear.

The Foot provides the support to the Human Body and plays an important role in the Weight Bearing and Weight Distribution aspects vis-à-vis the Kinetic Aspects of Human Movement is concerned. Kinematically, the Foot aids in propulsion and contributes to the Gait of the person and thus Foot Health is of paramount importance and all care must be taken to see that correct footwear is provided to prevent complications arising out of poor foot health. This would require additional care to see that the apt and correct fitting of the footwear on the foot is achieved and the proper ‘Last’ is used to
develop the most apt footwear which is comfortable for the wearer (Xiong and Goonetilleke 2008).

It would be impractical to develop a ‘Last’ for each and every individual and such an exercise would be time consuming and expensive. This type of Customised Last Development is suitable for persons having foot deformities or for those who suffer from foot complications due to lifestyle diseases like Diabetes or Obesity but for catering to the large majority of ‘normal’ persons we need to develop standardized lasts which would fit a vast majority of the people. To achieve this objective we use Advanced and Sophisticated Statistical Techniques to narrow down the number of lasts required to cater to the maximum number of people (Meyer 2006).

1.1 FIT

Foot problems will affect most of us at some point in our lives. One general recommendation that will ease the discomfort of most common foot problems is proper fitting shoes. Poorly fitting shoes can make symptoms of foot pain worse and in many cases be the primary cause of the problem (Akhtar et al 2008). It is important to purchase footwear that fits properly from the moment you buy them. Never buy footwear hoping they will “break in” later.

People are more than twice as likely to purchase their footwear too small. Signs that your shoes fit too small include “foot cramping” or “falling asleep” while walking or running as well as blistering on or between your toes. Properly fitted shoes allow adequate room to freely wiggle your toes. Poorly fitting shoes can also cause or aggravate bunions, calluses, hammertoes, and other common foot problems. For many people with more serious conditions like diabetes, proper fitting footwear is even more critical.
There are many things to consider when purchasing new footwear. The fit and support of the footwear are the two most important. You can benefit from having your feet measured and professionally fitted by experts who understand the way footwear is supposed to fit (Janisse 1992).

Here are some points to consider regarding proper shoe fit:

- Trying on shoes later in the day is always best. This will ensure your footwear fits correctly even if your feet have become more swollen throughout the day.

- Have both feet measured every year. Your left and right foot are most likely not the same size and may change in size from year to year. (your feet never stop changing)

- Always fit the larger foot. Adjustments can be made to your footwear to help fit the smaller foot.

- Purchase footwear that matches the general shape of your foot. (don’t try to fit a square peg in a round hole)

- The footwear must allow adequate toe room while standing. There should be 3/8” to ½” of space between your longest toe and the end of the shoe (approximately a thumb’s width)

- The widest part of your foot should sit in the widest part of the shoe

- Shoes should have a comfortable snug fit but should not feel tight or binding.
- Your heels should fit comfortably in your shoes with minimal slippage.

- Walk around in the shoe and be sure they feel comfortable. Make sure there are no pressure points from seams.

1.2 FOOTWEAR SIZING

When purchasing footwear it is important to recognize that you have a “foot size” and not a “shoe size.” Every footwear manufacturer will use different patented “lasts” or foot forms to make their footwear (Cheng and Perng, 1999). A size 8 for example will vary in fit from brand to brand and even between styles within the same brand. This is where the expertise of professional shoe fitters is a benefit as they understand the subtle differences in product fit between the many brands and styles. They also understand the fit differences between footwear categories.

Here is an example of some common fitting differences between the different categories of footwear.

If you wear a Men’s 8 in an athletic shoe you may likely wear a 7-7.5 in a dress shoe, a 7 in a steel toe work boot and an 8.5 or 9 in a snowmobile boot.

These sizes may vary again when we compare brands and specific styles.

1.2.1 Multiple-Width Fittings

A variety of quality footwear brands internationally offer multiple width fittings (Witana et al, 2004). The likelihood of finding footwear that fits you perfectly is much greater when you wear brands that offer multiple width
fittings. As with most things we wear, the correct width is as important as the correct length.

Here are the standard shoe widths you will find on most American footwear (Table 1.1).

**Table 1.1 Standard Shoe Widths in American Footwear**

<table>
<thead>
<tr>
<th>Women’s Shoe Widths</th>
<th>4A</th>
<th>2A</th>
<th>B</th>
<th>D</th>
<th>2E</th>
<th>4E</th>
</tr>
</thead>
<tbody>
<tr>
<td>X - Narrow</td>
<td>Narrow</td>
<td>Standard</td>
<td>Wide</td>
<td>X-Wide</td>
<td>XX - Wide</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Men’s Shoe Widths</th>
<th>2A</th>
<th>B</th>
<th>D</th>
<th>2E</th>
<th>4E</th>
<th>6E</th>
</tr>
</thead>
<tbody>
<tr>
<td>X- Narrow</td>
<td>Narrow</td>
<td>Standard</td>
<td>Wide</td>
<td>X-Wide</td>
<td>XX - Wide</td>
<td>Wide</td>
</tr>
</tbody>
</table>

Some brands may not use the above standardized widths and simply refer to their footwear as narrow, medium, wide etc. The key to remember is that in the end, the size and width written on the box doesn’t matter, it’s the FIT of shoe on your foot that matters! (Goonetilleke et al 1997). When choosing footwear and undecided between sizes, you are better off to choose the larger size. It is much easier to adjust the fit of a bigger shoe with socks, insoles or a different lacing pattern than it is to try and make a short shoe longer.

### 1.3 EVALUATING SHOE SUPPORT

There are several factors that determine whether a shoe will offer good support (Fong et al 2008), (Mundermann et al 2001):
**Heel Counter:** The heel counter is the hard piece in the back of the shoe that controls the foot's heel motion from side to side when you move. A strong heel counter increases stability providing better support for the foot (Gheluwe et al 1995). To quickly test the effectiveness of the shoe's heel counter, place the shoe in the palm of your hand and put your thumb in the mid-portion of the heel counter and try to push the back of the shoe. If the heel counter does not bend very much it is strong.

**Torsional Stability:** This checks for how easily the shoe twists. The shoe should have some flexibility, but if it bends very easily it is too flexible. The torsional stability of the shoe prevents the foot from being twisted or turned when in motion, helping to reduce muscle fatigue from compensating for the instability. If you hold the toe of the shoe in one hand and the heel in the other, twisting it in opposite directions with each hand should be quite difficult (Wannop et al 2010).

**Midfoot Bend Test:** The shoe should not bend in the middle (arch region). It should only bend at the ball of the foot, which matches where the foot would naturally bend. To test for this, hold the shoe in both hands at opposite ends, and try to bring your hands together. If the shoe bends very easily in the middle, as very soft-soled shoes often do, the shoe will not provide good stability to the foot.

**Removable Liners:** Shoes with removable liners are more versatile than those without them. Removable liners enable a knowledgeable footwear and foot orthotic expert to modify the shoe, if required, to help improve the function and fit of the shoe. A removable liner could also be replaced by a custom-made foot orthotic or an over-the-counter device, if necessary without greatly altering the fit of the shoe.
1.4 TYPES OF PEDORTHIC FOOTWEAR MODIFICATIONS

Footwear has come a long way in terms of offering orthopaedic / therapeutic features without affecting style, however sometimes the shoe may need modifying to produce better results (Whitney 2011). The types of modifications from the simple to complex and include:

- **Stretching:** stretching is a simple solution to improve the fit of a shoe. It can be done to a specific area of the foot (ball and ring stretcher) or for the whole forefoot.

- **Removing seams:** sometimes a shoe does not stretch well due to heavy seams that resist stretching; a Pedorthist can remove the stitches from certain areas of the shoe (i.e. the location of a painful bunion) to relax the materials without affecting the shoe.

- **Balloon patches:** should stretching and removing the seams be insufficient, Pedorthists may remove the material in a certain area, and add a balloon patch to increase the room in the shoe.

- **Sole splits:** the above modifications can increase the room available inside the shoe or decrease the stiffness of an area of the shoe. Often, the soles of the shoes can remain narrower than the upper portion of the shoe, which can pose problems. As the foot overlaps the narrow sole, this can result in increased pressure on certain parts of the foot as they "overhang" the sole; especially detrimental for people with diabetes and arthritis. Pedorthists may modify existing shoes
by "splitting" the sole in whatever area necessary and making the sole of the shoe wider by up to 3/8".

- **Excavations**: the inside of the shoe (i.e. ball of the foot or under the second toe) can be ground down in specific areas to reduce the pressure on sensitive areas.

- **Reinforcements**: if shoes tend to wear prematurely, Pedorthists can reinforce a patient's shoes with plastic inserts to reduce premature wear.

- **Flares and buttresses**: if reinforcements are still not sufficient to stop the foot from "rolling out" (supinating) or "rolling in" (pronating), Pedorthists may add material to the outside or inside edge of the shoes, respectively, to stop the foot from distorting the shoe. A flare is an addition to the sole of the shoe, whereas a buttress actually comes up against the leather part of the shoe as well as the sole (Brückner et al 2010).

- **Rocker soles**: a rocker sole can have several functions depending on where the fulcrum (tipping point) of the rocker is situated on the sole of the shoe. Rocker soles can be created to relieve pain in the ball of the foot or to improve gait for patients with fused ankles or fractured heel bones. Rocker soles can also aggressively offload certain areas of the foot for more acute conditions such as stress fractures or diabetic ulcers (Wertsch et al 1999).

- **Lifts**: without even knowing it, many people actually have a shorter leg which manifests itself in knee problems, lower
back pain, or foot problems strictly on one foot (usually the longer leg). To rectify this problem, Pedorthists may insert smaller lifts inside the shoe (internal lifts), up to 3/8" thick. More severe leg length differences can be corrected by the addition of material to the outside of the shoe, as part of the sole (external lifts).

These modifications can be made to everyday footwear - as well as athletic footwear. Pedorthists have the experience and knowledge to modify sports footwear such as hockey, speed or figure skates, and boots for hiking, skiing or snowboarding. Some modifications are not appropriate for all types of footwear and your options should be discussed carefully with a trained Pedorthist (Cheskin 2003).

1.5 FOOTWEAR – PROPER FITTING, CARE AND USAGE

Most people would agree that, like having a good mattress, good shoes are important to one’s well-being, since many hours are spent bearing weight on them. Yet people frequently buy ill-fitted shoes for fashion, price, or other reasons, and then keep wearing the shoes till they are worn out, because they have just become “broken in.”

Foot pain can be prevented or reduced from buying properly fitted shoes and proper footwear usage (Au and Goonetilleke 2007). Following are tips when purchasing shoes, aimed more for those buying running or exercise shoes, but also practical for the general population too. Also, tips on proper shoe care and use are presented.
1.5.1 Shoe Fitting

- Try on shoes in the afternoon or end of the day, or after a run or workout, since feet tend to become larger as the day progresses, by as much as a full size by the end of the day.

- Wear running socks when buying a new pair of running or exercise shoes.

- Always re-lace shoes being tried on.

- Stand when determining proper shoe fit.

- There should be approximately ½ inch of space between the end of your longest toe and the end of the toe box, or roughly your thumb width sideways.

- One should be able to wiggle one’s toes upwards.

- One should be able to squeeze a ripple in the shoe between the 1st and 5th toes, signifying adequate space in the toe box.

- Twist the shoe along its length to check for excessive flexibility.

- Squeeze the heel counter to check for firmness. It should be firm and difficult to pinch since it stabilizes and prevents slippage at the heel.

- Bend the front part of the shoe upwards. It should bend in the area of the toe-box. If the shoe bends in the area of the laces or midfoot, it is excessively flexible.
For running shoes, a padded collar around the top with a cut out for the Achilles tendon allows one to lace the shoe tightly.

Since one shoe may fit differently than the other, try them both on. Buy the size based on the larger foot.

When lacing up the shoe, the width of the lace holes should be the same all the way to the top. If not, it may be not the correct size.

One should know the type of foot one has when purchasing shoes, whether one has flat feet, high arches, or neutral feet. For example, a flat-footed person needs a motion control shoe, which is a stiffer, less flexible shoe to help decrease the excess motion inward seen with this type of foot. On the other hand someone with high arches needs a well-cushioned shoe to improve shock absorption since this person has a more rigid, less forgiving foot.

1.5.2 Other Considerations

Laced on shoes give a better fit than slip-ons.

Running shoes should be comfortable from Day 1. They shouldn’t have to be “broken in.”

If one participates in an exercise or sports specific activity, then a sport specific shoe is preferred.

With age the feet get fatter and longer, the feet and ankles become stiffer, and the arches tend to flatten.
1.5.3 Shoe use and Care

- Running shoes should be retired after 400-600 miles since the midsole begins to break down.

- For those who walk as exercise, shoes should be replaced roughly every 6 months. For normal use, sneakers should be replaced every year.

- Midsoles have a memory of 24-36 hours, so if one is running every day, the midsoles may not have time to spring back completely by the next run. Therefore, it is better to wear a different pair of shoes on alternate days.

- New shoes will break down over time, generally a year or two, if they are not worn.

- Machine washing and drying are very hard on shoes. If necessary, clean with dishwashing liquid, and then let the shoes air dry.

- Don’t use your other foot against a shoe’s heel counter to take off your shoe.

- Try not to run in wet shoes, since the cushioning may be compromised.

1.6 IMPORTANCE OF FITTING

As footwear retail continues to move towards self-service and internet sales, fitting issues become more important (Weston 2008). Not only
will there be an increased risk of product rejection at point of sale, but the seller will have few opportunities to obtain feedback on the reasons why.

One of the questions most frequently asked by the general public when purchasing footwear is, "why do marked shoe sizes appear to vary so much?"

The reasons can be linked to factors such as:

- No single unified and universally accepted shoe sizing and grading system, meaning manufacturers may use any of a number of different system (e.g. USA, English, Mondopoint or Paris Point)
- Customers may be confused by shoe size conversion between systems
- No universal accepted standardized last dimensions
- Fashion trends, e.g. toe shapes

All of these can have an effect on the overall fitting properties of the footwear.

Over the years, there has been a better understanding of the different fitting requirements across the globe. Today we have a good understanding of the needs of members worldwide and are able to offer advice recommendations relevant to different ethnic groups.

One of the major aims when developing footwear is to ensure that it is a suitable fit for the largest proportion of the intended market. To achieve this it is essential to have access to data that accurately defines the general
dimensions of feet and how these dimensions vary within the population. This type of data will usually be generated from national surveys.

1.6.1 How can fitting be defined?

At its simplest level, fitting can be defined as matching the internal shape and dimensions of the footwear to the foot it is intended to fit (Podiatry Channel 2009). In practice it is far more complex. For footwear to be considered to have the correct fitting properties it needs to be comfortable both when the foot is at rest and also in motion during wear. It must also have minimal adverse effects on the health and biomechanical function of the foot. Furthermore, these properties need to be retained throughout the lifetime of the shoe.

Research into fit over many years and some of the early studies provided the data that forms the basis of today’s guidelines. Work involved studying the importance of shape, the effects of design, processing, construction methods and materials. Studies on the differing needs of men, women and children have helped define the fitting standards needed for different end uses of footwear (for example, specialist sports shoes and safety footwear).

New Survey

A new survey recently carried in the UK surveyed 500 children aged from 6 months to 11 years. The aim was to establish whether the dimensions of children's feet had changed since the last survey and to determine the range of shoe sizes for a given age.

The survey indicated that growth of the foot up to four years of age had increased by one full English size (1/3" or 8.5 mm). However, the growth
above four years of age when compared against the previous survey data shows much the expected pattern.

In addition, the survey indicated that the parameters for a given age group had increased, expanding the required shoe size range to cover each age group.

1.6.2 What can affect the fit? Relationship between the foot and last

In theory, to achieve good fit, the shoe has to match the dimensions of the foot, provide a secure platform for the foot so that there is no unnecessary movement between foot and shoe, whilst avoiding points of high pressure (Goonetilleke et al 2000). At the same time, the shoe should not unduly distort the foot, particularly around the toes.

In practice, fit and comfort can be greatly influenced by the style of footwear particularly for women's fashion footwear. Here the last (and therefore the internal dimension of the shoe) has been developed to differ from the foot shape for the footwear to function and be aesthetically pleasing. This is especially so for high heeled courts (Vicenzino et al 2005). However, lasts developed for footwear with fastening systems (laces, elastic gussets, straps and buckles) can be more generous and still maintain acceptable levels of fit.

1.6.3 Material and footwear construction

Upper materials can play a significant part in the fitting properties of footwear in a number of different ways, mainly as a result of their modulus (tightness), plasticity (conformity of shape) and stiffness (ease of flexing). The variety of upper materials including leathers, synthetic materials, coated
fabrics and textiles now available to footwear manufactures is immense and the properties that can now be built into these materials is equally vast.

The bottom construction of the footwear has two major effects on the fitting characteristics of footwear. It can increase stiffness and hence prevent the foot flexing in the normal manner and the underfoot shape and the transverse curvature of the bottom can change the accommodation (volume) available for the foot.

1.6.4 A Good Fit is the Key to Footwear Sales

Achieving high levels of fit is a challenge that must be tackled, as it is fundamental to sales and the bottom line. “Fitting of footwear is often considered to be too difficult to get to grips with”. We've heard this said on various occasions. Each part of the supply chain is then left to take the proper measures to ensure that new products are developed correctly and accurately so that, when everything comes together, the shoes at retail will fit the customer and sell in great numbers (Wilson 2008).

However, such an approach can be very dangerous and costly. Even within the biggest global companies - those with extensive resources and which exert great control through the supply chain - examples can be found where products have failed to meet the required fitting standards, with significant financial penalties.

The world of shoe fitting is also changing. The footwear supply chain is more dispersed around the globe, with the product developer, last developer, last maker, upper assembler, shoemaker and retailer all perhaps being located in different countries. Electronic communication today is fast, but not necessarily easy. Technical requirements can be difficult to translate into other languages; customs and practices vary and they can be slow to
bring into corporate line or to co-ordinate. There is also a skills shortage when it comes to fitting - even in large companies, parts of the fitting process are understood by various parts of the supply chain, but few people know how to pull it all together successfully.

The importance of Proper Fit cannot be overly emphasized because wearing of ill-fitting footwear can lead to a lot of Foot related injuries and can lead to serious foot debilitation. Some of the Common Foot Injuries with their Causes and treatments are recounted below:

1.7 COMMON FOOT INJURIES

1.7.1 Achilles Tendonitis

![Achilles Tendonitis](image)

**Figure 1.1 Foot Injury - Achilles Tendonitis**

Achilles tendonitis (Figure 1.1) causes inflammation and degeneration of the achilles tendon. The achilles tendon is the large tendon located in the back of the leg that inserts into the heel. The pain caused by achilles tendonitis can develop gradually without a history of trauma. The pain can be a shooting pain, burning pain, or even an extremely piercing pain. Achilles tendonitis (Saltzman and Tearse 1998) should not be left untreated due to the danger that the tendon can become weak and ruptured. Achilles Tendonitis is aggravated by activities that repeatedly stress the tendon,
causing inflammation. In some cases even prolonged periods of standing can cause symptoms. It is a common problem often experienced by athletes, particularly distance runners. Achilles Tendonitis is a difficult injury to treat in athletes due to their high level of activity and reluctance to stop or slow down their training. Individuals who suffer from achilles tendonitis often complain that their first steps out of bed in the morning are extremely painful. Another common complaint is pain after steps are taken after long periods of sitting. This pain often lessens with activity.

There are several factors that can cause achilles tendonitis. The most common cause is over-pronation. Over-pronation occurs in the walking process, when the arch collapses upon weight bearing, adding stress on the achilles tendon. Other factors that lead to achilles tendonitis are improper shoe selection, inadequate stretching prior to engaging in athletics, a short achilles tendon, direct trauma (injury) to the tendon, and heel bone deformity.

Athletes, particularly runners, should incorporate a thorough stretching program to properly warm-up the muscles. They should decrease the distance of their walk or run, apply ice after the activity and avoid any uphill climbs. Athletes should use an orthotic device, heel cup, or heel cradle for extra support. A heel cup or heel cradle elevates the heel to reduce stress and pressure on the achilles tendon. The device should be made with light-weight, shock absorbing materials. An orthotic device can be used to control over-pronation, support the longitudinal arch, and reduce stress on the achilles tendon.
1.7.2 Arch Pain

The term arch pain (often referred to as arch strain) refers to an inflammation and/or burning sensation at the arch of the foot (Figure 1.2).

There are many different factors that can cause arch pain (Meisenbach 1916). A structural imbalance or an injury to the foot can often be the direct cause. However, most frequently the cause is a common condition called plantar fasciitis. The plantar fascia is a broad band of fibrous tissue located along the bottom surface of the foot that runs from the heel to the forefoot. Excessive stretching of the plantar fascia, usually due to overpronation (flat feet), causes plantar fasciitis. The inflammation caused by the plantar fascia being stretched away from the heel often leads to pain in the heel and arch areas. The pain is often extreme in the morning when an individual first gets out of bed or after a prolonged period of rest. If this condition is left untreated and strain on the longitudinal arch continues, a bony protrusion may develop, known as a heel spur. It is important to treat the condition promptly before it worsens.

This is a common foot condition that can be easily treated. If you suffer from arch pain avoid high-heeled shoes whenever possible. Try to choose footwear with a reasonable heel, soft leather uppers, shock absorbing
soles and removable foot insoles. When the arch pain is pronation related (flat feet), an orthotic designed with a medial heel post and proper arch support is recommended for treating the pain. This type of orthotic will control over-pronation, support the arch and provide the necessary relief.

1.7.3 Bunion

![Figure 1.3 Foot Injury – Bunion](image)

Bunions (Figure 1.3), referred to in the medical community as Hallux Valgus, are one of the most common forefoot problems. A bunion is a prominent bump on the inside of the foot around the big toe joint. This bump is actually a bone protruding towards the inside of the foot. With the continued movement of the big toe towards the smaller toes, it is common to find the big toe resting under or over the second toe. This causes a common forefoot condition called overlapping toes. Some of the symptoms of bunions include inflammation, swelling, and soreness on the side surface of the big toe. The discomfort commonly causes a patient to walk improperly.

Another type of bunion which some individuals experience is called a Tailor's Bunion, also known as a Bunionette. This forms on the outside of the foot towards the joint at the little toe. It is a smaller bump that forms due to the little toe moving inwards, towards the big toe.
Bunions are a common problem experienced mostly by women. The deformity can develop from an abnormality in foot function, or arthritis, but is more commonly caused by wearing improper fitting footwear. Tight, narrow dress shoes with a constrictive toe box (toe area) can cause the foot to begin to take the shape of the shoe, leading to the formation of a bunion. Women who have bunions normally wear dress shoes that are too small for their feet. Their toes are squeezed together in their shoes causing the first metatarsal bone to protrude on the side of the foot.

It is important for men and women to realize that wearing dress shoes and boots, which are tapered in the toe area, can cause the bunion to worsen to the point where surgery is necessary.

In the early stages of the formation of a bunion, soaking feet in warm water can provide temporary relief. The best way to alleviate the pain associated with bunions is to wear properly fitting shoes. Shoes designed with a high, wide toe box (toe area) are recommended for people suffering from forefoot disorders, such as bunions. Shoes with rocker soles will unload pressure to the bunion area. Orthotics are also recommended for this condition to provide extra comfort, support, and protection.

Other conservative treatments include using forefoot products designed to accommodate and relieve bunions such as bunion shields, bunion night splints, and bunion bandages. These conservative treatments can limit the progression of the bunion formation, relieve pain and provide a healthy environment for the foot. In extreme cases, surgical intervention is prescribed (Scranton 1983).
1.7.4 Callus

The formation of calluses (Figure 1.4) is caused by an accumulation of dead skin cells that harden and thicken over an area of the foot. This callus formation is the body's defence mechanism to protect the foot against excessive pressure and friction. Calluses are normally found on the ball-of-the-foot, the heel, and/or the inside of the big toe. Some calluses have a deep seated core known as a nucleation. This particular type of callus can be especially painful to pressure. This condition is often referred to as Intractable Plantar Keratosis.

Calluses develop because of excessive pressure at a specific area of the foot. Some common causes of callus formation are high-heeled dress shoes, shoes that are too small, obesity, abnormalities in the gait cycle (walking motion), flat feet, high arched feet, bony prominences, and the loss of the fat pad on the bottom of the foot.

Many people try to alleviate the pain caused by calluses by cutting or trimming them with a razor blade or knife. This is not the way to properly treat calluses. This is very dangerous and can worsen the condition resulting
in unnecessary injuries. Diabetics especially should never try this type of treatment. To relieve the excessive pressure that leads to callus formation, weight should be redistributed equally with the use of an orthotic. An effective orthotic transfers pressure away from the "hot spots" or high pressured areas to allow the callus to heal (Akdemir 2011). The orthotic should be made with materials that absorb shock and shear (friction) forces. Women should also steer away from wearing high-heeled shoes. As always, surgery should be the very last resort.

1.7.5 Claw Toe

![Figure 1.5 Foot Injury – Claw Toe](image)

A claw toe (Figure 1.5) is a toe that is contracted at middle and end joints in the toe and can lead to severe pressure and pain. Ligaments and tendons that have tightened cause the toe's joints to curl downwards. Claw toes may occur in any toe, except the big toe (Schnepp 1993). There is often discomfort at the top part of the toe that is rubbing against the shoe and at the end of the toe that is pressed against the bottom of the shoe. Claw toes are classified based on the mobility of the toe joints. There are two types - flexible and rigid. In a flexible claw toe, the joint has the ability to move. This type of claw toe can be straightened manually. A rigid claw toe does not have that same ability to move. Movement is very limited and can be extremely painful. This sometimes causes foot movement to become restricted leading
to extra stress at the ball-of-the-foot, and possibly causing pain and the development of corns and calluses.

Claw toes result from a muscle imbalance which causes the ligaments and tendons to become unnaturally tight. This results in the joints curling downwards. Arthritis can also lead to many different forefoot deformities, including claw toes.

Changing the type of footwear worn is a very important step in the treatment of claw toes. When choosing a shoe, make sure the toe box (toe area) is high and broad, and can accommodate the claw toes. A shoe with a high, broad toe box will provide enough room in the forefoot area so that there is less friction against the toes. Other conservative treatments include using forefoot products designed to relieve claw toes, such as toe crests and hammer toe splints. These devices will help hold down the claw toe and provide relief to the forefoot. Gel toe shields and gel toe caps are also recommended to eliminate friction between the shoe and the toe, while providing comfort and lubrication.

1.7.6 Corn

![Figure 1.6 Foot Injury – Corn](image)
Corns (Figure 1.6), like calluses, develop from an accumulation of dead skin cells on the foot, forming thick, hardened areas. They contain a cone-shaped core with a point that can press on a nerve below, causing pain. Corns are very common ailments that usually form on the tops, sides and tips of the toes. Corns can become inflamed due to constant friction and pressure from footwear. Corns that form between the toes are sometimes referred to as soft corns.

Some of the common causes of corn development are tight fitting footwear, high heeled footwear, tight fitting stockings and socks, deformed toes, or the foot sliding forward in a shoe that fits too loosely (Springett et al 2003). Soft corns result from bony prominences and are located between the toes. They become soft due to perspiration in the forefoot area. Complications that can arise from corns include bursitis and the development of an ulcer.

There are very simple ways to prevent and treat the corns. You should wear properly fitted footwear with extra room in the toe box (toe area). Avoid shoes that are too tight or too loose. Use an orthotic or shoe insert made with materials that will absorb shock and shear forces. Also avoid tight socks and stockings to provide a healthier environment for the foot. Try to steer away from corn removing solutions and medicated pads. These solutions can sometimes increase irritation and discomfort. Diabetics and all other individuals with poor circulation should never use any chemical agents to remove corns.
1.7.7 Hammer Toe

Figure 1.7 Foot Injury – Hammer Toe

A hammer toe (Figure 1.7) is a toe that is contracted at the middle joint in the toe, potentially leading to severe pressure and pain. Ligaments and tendons that have tightened cause the toe's joints to curl downwards. Hammer toes may occur in any toe except the big toe. There is often discomfort at the top part of the toe due to rubbing against the shoe. Hammer toes are classified based on the mobility of the toe joints. There are two types - flexible and rigid. In a flexible hammer toe, the joint has the ability to move. This type of hammer toe can be straightened manually. A rigid hammer toe does not have that same ability to move. Movement is very limited and can be extremely painful. This sometimes causes foot movement to become restricted leading to extra stress at the ball-of-the-foot, and possibly causing pain and the development of corns and calluses. Follow this link to learn more about hammer toe products.

Hammer toes result from a muscle imbalance which causes the ligaments and tendons to become unnaturally tight (Dhukaram et al 2002). This results in the joint curling downward. Arthritis can also lead to many different forefoot deformities, including hammer toes.
Changing the type of footwear worn is a very important step in the treatment of hammer toes. When choosing a shoe, make sure the toe box (toe area) is high and broad, and can accommodate the hammer toes. A shoe with a high, broad toe box will provide enough room in the forefoot area so that there is less friction against the toes. Other conservative treatments include using forefoot products designed to relieve hammer toes, such as hammer toe crests and hammer toe splints. These devices will help hold down the hammer toe and provide relief to the forefoot. Gel toe shields and gel toe caps are also recommended to eliminate friction between the shoe and the toe, while providing comfort and lubrication.

1.7.8 Heel Spur

The heel bone is the largest bone in the foot and absorbs the most amount of shock and pressure. A heel spur (Figure 1.8) develops as an abnormal growth of the heel bone. Calcium deposits form when the plantar fascia pulls away from the heel area, causing a bony protrusion, or heel spur to develop. The plantar fascia is a broad band of fibrous tissue located along the bottom surface of the foot that runs from the heel to the forefoot. Heel spurs can cause extreme pain in the rearfoot, especially while standing or walking.
Heel spurs develop as an abnormal growth in the heel bone due to calcium deposits that form when the plantar fascia pulls away from the heel. This stretching of the plantar fascia is usually the result of over-pronation (flat feet), but people with unusually high arches (pes cavus) can also develop heel spurs (Wainwright et al 1995). Women have a significantly higher incidence of heel spurs due to the types of footwear often worn on a regular basis.

The key for the proper treatment of heel spurs is determining what is causing the excessive stretching of the plantar fascia. When the cause is over-pronation (flat feet), an orthotic with rearfoot posting and longitudinal arch support is an effective device to reduce the over-pronation, and allow the condition to heal. Other common treatments include stretching exercises, losing weight, wearing shoes that have a cushioned heel that absorbs shock, and elevating the heel with the use of a heel cradle, heel cup, or orthotic. Heel cradles and heel cups provide extra comfort and cushion to the heel, and reduce the amount of shock and shear forces experienced.

1.7.9 Heel Pain

Figure 1.9 Foot Injury – Heel Pain

Heel pain (Figure 1.9) is a common condition in which weight bearing on the heel causes extreme discomfort. There are two different categories of heel pain. The first is caused by over-use repetitive stress which refers to a soreness resulting from too much impact on a specific area of the
foot. This condition often referred to as "heel pain syndrome," can be caused by shoes with heels that are too low, a thinned out fat pad in the heel area, or from a sudden increase in activity. Plantar fasciitis, a very common diagnosis of heel pain, is usually caused from a biomechanical problem, such as over-pronation (flat feet). The plantar fascia is a broad band of fibrous tissue that runs along the bottom surface of the foot, from the heel through the midfoot and into the forefoot. Over-pronation can cause the plantar fascia to be excessively stretched and inflamed, resulting in pain in the heel and arch areas of the foot (Irving et al 2006). Often the pain will be most intense first thing in the morning or after a prolonged period of rest. The pain will gradually subside as the day progresses.

To properly treat heel pain, you must absorb shock, provide cushioning and elevate the heel to transfer pressure. This can be accomplished with a heel cup, visco heel cradle, or an orthotic designed with materials that will absorb shock and shear forces. When the condition is pronation related (usually plantar fasciitis), an orthotic with medial posting and good arch support will control the pronation and prevent the inflammation of the plantar fascia. Footwear selection is also an important criteria when treating heel pain. Shoes with a firm heel counter, good arch support, and appropriate heel height are the ideal choice.

1.7.10 Metatarsalgia

Figure 1.10 Foot Injury – Metatarsalgia
Metatarsalgia (Figure 1.10) is a general term used to denote a painful foot condition in the metatarsal region of the foot (the area just before the toes, more commonly referred to as the ball-of-the-foot). This is a common foot disorder that can affect the bones and joints at the ball-of-the-foot. Metatarsalgia (ball-of-foot-pain) is often located under the 2nd, 3rd, and 4th metatarsal heads, or more isolated at the first metatarsal head (near the big toe).

With this common foot condition, one or more of the metatarsal heads become painful and/or inflamed, usually due to excessive pressure over a long period of time (Espinosa et al 2010). It is common to experience acute, recurrent, or chronic pain with metatarsalgia. Ball-of-foot pain is often caused from improper fitting footwear, most frequently by women's dress shoes and other restrictive footwear. Footwear with a narrow toe box (toe area) forces the ball-of-foot area to be forced into a minimal amount of space. This can inhibit the walking process and lead to extreme discomfort in the forefoot. Other factors can cause excessive pressure in the ball-of-foot area that can result in metatarsalgia. These include shoes with heels that are too high or participating in high impact activities without proper footwear and/or orthotics. Also as we get older, the fat pad in our foot tends to thin out, making us much more susceptible to pain in the ball-of-the-foot.

The first step in treating metatarsalgia is to determine the cause of the pain. If improper fitting footwear is the cause of the pain, the footwear must be changed. Footwear designed with a high, wide toe box (toe area) and a rocker sole is ideal for treating metatarsalgia. The high, wide toe box allows the foot to spread out while the rocker sole reduces stress on the ball-of-the-foot. Unloading pressure to the ball-of-the-foot can be accomplished with a variety of footcare products. Orthotics designed to relieve ball-of-foot pain usually feature a metatarsal pad. The orthotic is constructed with the pad.
placed behind the ball-of-the-foot to relieve pressure and redistribute weight from the painful area to more tolerant areas. Other products often recommended include gel metatarsal cushions and metatarsal bandages. When these products are used with proper footwear, you should experience significant relief.

1.7.11 Morton’s Neuroma

![Figure 1.11 Foot Injury – Morton’s Neuroma](image)

Morton's Neuroma (Figure 1.11) is a common foot problem associated with pain, swelling and/or an inflammation of a nerve, usually at the ball-of-the-foot between the 3rd and 4th toes. Symptoms of this condition include sharp pain, burning, and even a lack of feeling in the affected area. Morton's Neuroma may also cause numbness, tingling, or cramping in the forefoot.

Morton's Neuroma is a foot condition caused from an abnormal function of the foot that leads to bones squeezing a nerve usually between the 3rd and 4th metatarsal heads (Thomas et al 2009). Symptoms of Morton's Neuroma often occur during or after you have been placing significant pressure on the forefoot area, while walking, standing, jumping, or sprinting. This condition can also be caused by footwear selection. Footwear with
pointed toes and/or high heels can often lead to a neuroma. Constricting shoes can pinch the nerve between the toes, causing discomfort and extreme pain.

The first step in treating Morton's Neuroma is to select proper footwear. Footwear with a high and wide toe box (toe area) is ideal for treating and relieving the pain. The next step in treatment is to use an orthotic designed with a metatarsal pad. This pad is located behind the ball-of-the-foot to unload pressure, and relieve the pain caused by the neuroma.

1.8 COMFORT

Although, new materials, footwear design and technology can enhance shoe comfort, the most important comfort factor is getting the right fit. Feet are not standard - they are highly individual. Apart from foot shape, factors such as physiology and gait need to be taken into account. One man's ‘comfort shoe' may be the cause of discomfort for someone else, or comfortable for the first three hours of wear, then a source of pain and blisters.

Most people when sizing is mentioned think of length of the shoe only, when in fact tread width and toe depth are also vital measurements when assessing the "comfort" of a shoe for any particular wearer (Jordan and Bartlett 1995).

It is a combination of all three measurements that make a shoe "comfortable". Without the correct width and toe depth a shoe is never going to feel "comfortable". This varies for each individual wearer, as all our foot shapes are different. It is only once these factors have been taken into account that other factors such as soling materials, upper materials etc., then add to the "comfort" experience (Mills et al 2010).
Many of the “comfort shoes” have removable socks allowing a podiatrist to insert specialist orthotic devices if required; other styles are seam free on the inside, a possible choice for people who have diabetes or other foot health issues.

Obviously it is vital to wear the right shoe for the right occasion, but it is important to buy a good quality shoe that fits snugly at the heel, nicely across the breadth and with ample provision for toes. These points tick most of the boxes - but there is so much more to take into consideration which can only come from an educated and practiced eye.

Comfort, however, is only one factor amongst a multitude of considerations. Fitness for purpose is essential and comfort does not necessarily imply that fitness for purpose has been attained (Nigg et al 1999). This would include considerations of the overall suitability of the shoe for wearing on the foot as well as the need for that shoe to fit well and be matched to the purpose intended.

1.8.1 Making Comfortable Footwear

How can comfortable footwear be made? The diversity of footwear types, individuality of wearers and range of end-use applications means that there can be no simple answer to this question. Even if making bespoke footwear for an individual with a specific use in mind, it is extremely difficult to produce a comfort specification without first trying a selection of prototype sample variations to determine what most suits that individual (Wilson 2009).

There are, however, a number of principles and key comfort attributes that can be widely applicable to many types of mass-market footwear. In this article, we offer an approach to follow, to help analyse and
define comfort objectives. We then look at the key physical factors important in designing comfortable footwear.

Finally, we consider briefly the execution phase of the process - the shoemaking.

1.8.2 Satisfying the Mass Market

'Comfort' (defined as 'the absence of discomfort') can be universally applied to all types of footwear and all markets. Unfortunately, the causes of discomfort are manifold and the type of discomfort is often directly associated with the end use - for example, hot feet in hot climates or workplaces, sore heels and balls of the feet from waking on hard surfaces, cramped toes and blisters from sliding forwards when wearing high-heeled footwear or from rapid changes in direction when playing sports (Finestone et al 2004).

Individuals vary enormously in their foot shape, physiology (such as sweat rates and skin sensitivity), gait and personal tolerances (Hawes et al 1994). So, in terms of comfort, it is unlikely that everyone buying a particular product, no matter how good it appears to be, will be entirely satisfied and free of discomfort. The majority of people may find that the product initially feels comfortable and remains so for two or three hours on the foot. However, for some people, over the course of a long working day, the repeated forces and strains on the feet build up and discomfort develops.

The market for a particular product also has to be carefully thought through and the implications considered. Gender is the obvious starting point, as men's and women's feet differ in a number of ways. For instance, the female heel width is narrower relative to foot length and forefoot width than the male heel.
Many manufacturers minimize production costs by simply making women's shoes as a smaller version of their men's shoes, but this will not suit many women.

**1.8.3 Changing comfort needs**

The target customer's age group is the next comfort factor, as feet change with age. There are significant alterations in foot shape from childhood to adolescence and into adulthood, with more changes again in later years - mainly after wearers pass the age of 60. During childhood, the foot may grow in length at an average of about 8mm per year and have a lot of fatty tissue surrounding the developing bones. Young women in the 16-25 age group typically have feet which are one to one and a half fittings slimmer than their counterparts of 56 years-old plus.

Feet also change shape and size for other reasons, including obesity, fluid retention as result of illness, ageing or foot injury - either from trauma accidents or because of wearing ill-fitting footwear (Miller et al 2000). During pregnancy, about 50-75 per cent of women will experience an increase of half a shoe size or more. Some will not return to their original shoe size.

Associated with these physical changes may be changing comfort requirements. The ageing body loses its natural elasticity, flexibility and resilience and, therefore, increased levels of cushioning and flexibility in footwear is desirable. Greater adjustability in fastening systems will give comfort to more wearers.

In addition to the mass market, there are many niche markets where comfort takes on a special significance. For instance, people with advance diabetes will lose sensation in their feet and the skin is highly susceptible to injury from ill-fitting footwear, rough lining materials and seams.
1.8.4 Improvements in Comfort

By taking a fresh look at the intended market, much may be learned about comfort from analyzing sales figures, returns and complaints. This will depend, however, on the quality of the information gathered about customers - particularly their ages and what other brands or types of footwear they usually buy.

Sales figures will show which types of solings or upper materials are used in the best-selling lines or which constructions and upper styles are most popular. Comparing batch-on-batch or year-on-year sales figures of long-running lines may indicate where changes in materials or components may have influenced sales.

'Fit' is often an option on a returns questionnaire that is used by the customer as an easy way of justifying returning a product, and it thus becomes an unhelpful 'catch-all tick box'. It would be better broken down into further categories, such as "too long or short", "too wide or narrow' or "other discomfort - please specify'.

Fit assessments and wear trials produce more precise comfort information. The SATRA Comfort Index is specifically designed to identify the strengths and weaknesses of footwear designs in terms of comfort (Wilson 2007).

With experience of footwear fitting and comfort assessment, it is found that a number of causes of discomfort occur most often and apply equally to many different types of men's and women's footwear (Wunderlich and Cavanagh 2001). In no particular order, they are:
- Back and quarter heights being too high or too low, with back tabs exerting pressure; poor shape and heat setting of backparts
- Heel slip due to the above or other factors
- Tongue being too high or too stiff
- Elastic gussets not functioning on slip-on footwear
- Facings butting, limiting adjustment on slimmer feet
- Excessive volume in forepart causing sharp vamp creases
- Box toe (toe puff) or toe cap too long, concentrating flex creases in narrow area
- Inadequate allowance for insock thickness or padded upper linings reducing internal volume
- Incorrectly-pitched heel causing insecurity and topline problems
- Low throat and side heights not giving adequate foot coverage for security (women's footwear)
- Intrusive arch supports
- Inadequate underfoot cushioning.

On the basis that 'comfort is the absence of discomfort', these factors should be at the top of any comfort check list.
1.8.5 Limits on comfort

It must be recognized that there will be an inherent limit on the level of comfort that can be achieved in some types of footwear. For example, traditional boat shoes (moccasin construction) and men’s and women’s dress shoes could not be designed to give the same level of underfoot cushioning and shock absorption as sports shoes without fundamentally changing their appearance. The sole thickness would have to be increased, and a substantial layer of compressible soling or midsoling material added, thus changing the nature of the product (Bates et al 1979).

Appearance requirements can be another limitation. A durable and shiny patent look cannot be achieved at the same time as softness and flexibility. A smart, well-formed toe with a long box toe (toe puff) that is both durable and resilient is liable to have a degree of stiffness that will transfer flexing and movement to other areas of the upper.

Furthermore, a manufacturer will be constrained by the range of types of footwear constructions and shoemaking processes available. Changing from a flat-last construction with an insole board to force lasting with a sewn-in sock, or from stuck-on solings to direct-moulded, requires a significant investment in plant and re-training of operatives.

1.8.6 Comfort criteria

So, what is the key to designing and making comfortable footwear? (Mundermann et al 2002). How can all potential causes of discomfort be eliminated and comfort performance enhanced for the customer?

The key is to make footwear that readily accommodates a reasonable range of normal (typical) variations in foot shape, and which will
facilitate normal dynamic foot functions. It must achieve both these goals without exerting undue pressure on any point on the foot, which is the most common cause of discomfort. The footwear may also be required to provide a degree of support and physical protection from the surroundings (Bird and Payne 1999), particularly on hard, rough or uneven ground, as well as from knocks and scratches (Baitch et al 1991).

In addition, the footwear will have to deal with the thermoregulation (temperature control) and moisture (sweat) management requirements of the wearer in his or her given activities and environment. This may mean keeping the foot dry and warm in wet and cold conditions, or keeping it cool and dry in hot conditions or when undertaking strenuous exercise. Some of these requirements can work against others. For example, underfoot cushioning reduces pressure, but it can work against support and stability. Physical exercise - even in cold climates - generates heat and sweat, so footwear for this application requires insulation for static or rest periods, and good heat and moisture disposal during activity (Novick and Kelley 1990). It is necessary, therefore, to decide on priorities for the given end use, and perhaps to accept some compromises.

1.8.7 Universal comfort design principles

It cannot be stated too often that fit is the number one comfort factor. Material selection, footwear construction and good shoemaking will enhance comfort, but are no substitutes for good fundamental fitting properties (Blanch et al 2010).
To achieve the key comfort requirements above, the footwear must therefore have:

- Correct length, width and girth dimensions across an appropriate size range centred on the average dimensions for the corresponding foot size of the intended market
- The ability to comfortably accommodate a range of normal foot shapes centred on the average shape
- The capacity to accommodate the increase in foot length, and volume changes in foot size and shape that occur during gait. As the foot hits the ground at heel strike and rolls through to forefoot flexing and take-off, the 26 bones and 33 joints in each foot deflect and spread under bodyweight load (Jarboe and Quesada 2003).

Depending on the level of comfort required and the restrictions imposed by the end-use application, the footwear should ideally have:

- An adjustable fastening system or low modulus - the stretch and recovery properties of linings and outer materials which readily conform to foot shape
- Whole shoe flexibility (sole and upper) in torsion and across the joint
- No hard or rigid components
- A lightweight construction
- Underfoot cushioning incorporated.
To save the wearer having to make significant gait adjustments to accommodate shoe design, footwear should also have:

- A low heel height
- A broad, stable heel base
- Forepart tread width just slightly wider than the foot
- Appropriate toe spring.

High heels, underset small top-pieces and inappropriate toe spring for the given forepart stiffness of the footwear will all impair the natural walking action and will apply different forces and pressures on the foot (Sussman and Amico 1984). This could result in small changes to the gait pattern, some of which will occur subconsciously (Lee et al 2001).

1.8.8 Key Principles of Underfoot Comfort

The most important principle to address here is the elimination of underfoot 'hot spots'. This does not necessarily mean 'hot' purely in terms of temperature, but also in terms of pressure and effects which may produce a sensation of heat.

In virtually all types of footwear, the wearer will benefit from a layer of underfoot cushioning, which is most effective if placed next to the foot in the insock or footbed (Merriman 2002). The insock can be designed to reduce pressure through its compression properties and to minimize frictional rubbing through its shear modulus properties and surface friction characteristics (Nigg and Koning 1994).

Underfoot comfort can be further enhanced in suitable footwear types by incorporating shock absorption and energy return properties into the
midsole and/or outsole. It is, however, very difficult to be prescriptive about the ideal or optimum levels of cushioning, shock absorption and energy return for different applications, as they can be interdependent on each other and on other factors, such as footwear stiffness (Hutchins et al 2009).

Cushioning underfoot also contributes to ground insulation - the prevention of feel-through of stones and rough underfoot surfaces. For example, a cushioning (soft) outsole can absorb small stones into its surface without transmitting high pressure to the foot. Ground insulation can also be achieved by using stiff or rigid materials in the bottom construction that will bridge across stones and unevenness in the walking surface.

In certain applications, ground insulation is not required. For example, the visually impaired can benefit from wearing shoes through which they can feel the studded pavement slab which warns them of traffic crossings.

1.8.9 Upper Comfort - Key Principles

Upper comfort is particularly critical in women's fashion footwear, where the pressures on the top of the foot and toes are greatest due to heel height and styling demands of fashion. However, the same principles apply to all footwear types, as any pressure point will eventually lead to discomfort (McPoil 1988).

Stretch and recovery properties - the material modulus - is the key consideration, along with softness, flexibility and texture. These properties are often grouped together and are very difficult to measure in a simple, meaningful way that directly relates to wearer comfort.
A balance must be sought between lines of tightness in the upper over the foot where support and security is required for foot comfort, accommodation of different foot shapes and elimination of pressure points. The two areas to concentrate on are the backpart and the joint, as these are the areas that locate and hold the foot in the correct alignment in the footwear. The foot needs to be held here securely but sensitively. Of course, in the case of mule-type footwear and strappy sandals, there is only the joint to consider.

Seam and strap location is important. Seams should not coincide with the main contact points with the foot, where the risk of creating a 'hotspot' is greatest. Straps should apply an even pressure to the skin and bone that they are covering. Care should be taken in the use of elastics, particularly when incorporated in straps. The intention may be to make the accommodation of different foot shapes easier but, by allowing the strap to stretch easily, support and security may be impaired and this may allow heel slip - for instance, in the backpart fit. Where straps are adjustable by means of buckles or touch-and-close fasteners, elastic may not be beneficial. Where elastic is used, it should have reasonably high modulus to allow some stretch, but not an excessive amount (Frey 2000).

1.8.10 Moisture management

When wearers become hot due to exercise or a high ambient temperature, their feet will sweat more. The moisture produced should not be allowed to build up next to the skin. The footwear linings, including the insock, should wick and/or absorb moisture away from the skin and hose. Ideally, the moisture should then continue to be moved away from the foot and expelled from the footwear altogether by permeation, evaporation and ventilation (Garrow et al 2006).
Material selection is important in this area of the shoe. It is potentially misleading, however, to try to generalize about the performance properties of different types of material, because of the wide variations within a given material type such as leather, coated fabric and textile (Table 1.2). There are also many different treatments and finishes that can be applied to modify the performance properties.

There are a number of simple material tests for wicking, absorption, desorption, permeability and thermal insulation. The Advanced Moisture Management Test (AMMT) - SATRA TM376 (Table 1.3) goes one step further by taking account of all the different materials that may be used in a shoe or boot construction and the compatibility between them.

Table 1.2 Typical permeability performance levels of commonly used materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Water vapour permeability (mg/cmVh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suedes, nubucks, calf leathers</td>
<td>&gt;5</td>
</tr>
<tr>
<td>Full-grain leathers</td>
<td>2-5</td>
</tr>
<tr>
<td>Corrected grain leathers</td>
<td>1 - 2 (will increase significantly during wear)</td>
</tr>
<tr>
<td>Permeable-coated leathers and most PU-based poromeric</td>
<td>0.5 - 2.0</td>
</tr>
<tr>
<td>Polyurethane-coated fabrics (PUCFs)</td>
<td>0.5-15</td>
</tr>
<tr>
<td>Coated splits, patent leathers, PVC-coated fabrics</td>
<td>&lt;05</td>
</tr>
</tbody>
</table>
Table 1.3  SATRA Advanced Moisture Management test (SATRA TM376) guidelines for comfort

<table>
<thead>
<tr>
<th>Performance Rating</th>
<th>Internal moisture transfer -relevant to short-term comfort. Measured by hose gain (g)</th>
<th>External breathability -relevant to long-term comfort. Measured by evaporation loss (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor moisture management properties</td>
<td>6 and above</td>
<td>2.9 or less</td>
</tr>
<tr>
<td>Average moisture management properties</td>
<td>4-5.9</td>
<td>3-5.9</td>
</tr>
<tr>
<td>Good moisture management properties</td>
<td>3.9 or less</td>
<td>6 and above</td>
</tr>
</tbody>
</table>

1.8.11  The 'balanced' shoe concept

Some of the most comfortable shoes that we see are what might be described as "well balanced' products. They are usually of a quite simple design, using a limited number of different materials which work well together. The soling and upper are compatible in terms of softness and flexibility, and combine together to make a compliant, flexible featherline. The degree of cushioning and cosseting is uniform over the whole inside surface of the shoe (Dai et al 2006). Most importantly, the shoes fit well, readily conforming to slightly different foot shapes of different wearers.
Examples of unbalanced shoes include those which might have a thin, unsupported upper on a thick, stiff sole or upper panels of soft and stretchy materials held between ribs of relatively harsh, high modulus materials. They may also have different lining materials on the counter, quarters and vamp, as well as tight, coated fabric straps with weak elastic inserts or a nicely-padded tongue but a bulky, rough seam where it is sewn in at the throat.

Poor shoemaking practice can quickly destroy all the effort put into designing and assembling a comfortable shoe. Some examples include:

- Insufficient skiving of upper seams, leaving excess bulk and prominent edges that may rub against the foot. Likewise, box toes (toe puffs) and counters (stiffeners) should be skived at the edges to blend in gently with the upper and to avoid presenting hard edges - for instance, under the ankle bone.

- Poorly-finished seams where thread ends have been left loose, possibly hardened by heat or knotted heavier threads - as an example, at the tabs of moccasin apron seams.

- Application of excessive adhesive when combining linings, interlinings and outer materials is likely to destroy moisture permeability and, therefore, seriously affect moisture management in an adverse way.

- A lack of production control of mould temperatures and cooling times at back part moulding can result in distorted back parts affecting fit and comfort (Witana et al 2009).
Inadequate conditioning and heat setting of lasted uppers or poor process control. Moisture content level is important with leathers, while temperature is critical with coated leathers and fabrics. Getting the right combination of heat, moisture and timing for different uppers is essential to avoid upper distortion and fall-in when the last is removed.

- Shrinkage and distortion of EVA, micro-rubber and crepe rubber solings due to storage or use in extreme environments. These are post production, in-service problems. However, susceptibility to shrinkage may be traced back to insufficient post-process heat curing in the factory.

These are all potential causes of discomfort and, therefore, must be eliminated.

1.8.12 Benchmarking

If comfort is a key selling point for your brand, then you should consider drawing up a comfort specification on similar lines to a product quality specification. This would define the target market and its needs as discussed at the beginning of this article. It would go on to specify material comfort properties, such as modulus, permeability and cushioning, depending on the component. Also specified would be whole shoe comfort properties, including shock absorption, whole shoe moisture management, and even a Comfort Index. Finally, it might include a list of shoemaking process checks to eliminate those potential pitfalls identified above.

To help set up comfort specifications, it is helpful to undertake some benchmark testing of current products and then to base the target performance levels around or slightly above what is already known to be achievable.
1.8.13 SATRA Comfort Index

SATRA's unique Comfort Index is a means to measure overall footwear comfort in a controlled laboratory environment. It comprises four elements: fit assessment, aesthetics and handle (softness, flexibility and texture), moisture disposal assessment and treadmill assessment. A scoring system assigns marks to over 60 individually assessed comfort factors.

Fit assessment identifies problems in accommodating the target market population and specific fitting faults that might lead to discomfort. Aesthetics and handle uses a panel of assessors to systematically evaluate the feel and handle of materials and whole shoe construction. Thus, the customer's perception of comfort at point of sale - which influences the buying decision process - is evaluated.

Moisture disposal properties of upper, lining and insock materials are considered with respect to wicking, absorption and permeability performance, and the overall ability of the footwear to manage sweat production. The key part of the Comfort Index is the assessment of physical comfort parameters on the foot during treadmill walking. Trained wearers respond to questions about different comfort factors of the shoe while walking on a treadmill at a set speed in the laboratory. Standard hose is worn and, before each test, a reference shoe is worn to standardise the procedure. Multi-choice answers are shown to the wearers while walking so each one can be fully considered.

The final Comfort Index is calculated by combining all the scores and applying weighting factors reflecting the relative importance of each parameter. An Index below a certain number is rated as ‘uncomfortable’, with rising levels of comfort measured from ‘moderately comfortable’ to ‘highly comfortable’ at a high Index number.
According to SATRA its Comfort Index provides a meaningful, quantified method of measuring comfort, which can differentiate between products as well as between materials or components in similar shoes. It quickly identifies the comfort strengths and weaknesses of new designs without the need for expensive and time-consuming wear trials, providing pointers to where product improvements can be made.

1.9 LAST DIMENSIONS and PARAMETERS

1.9.1 Assessing lasts to optimize shoe fit and comfort

The dimensions and shape of the last are crucial to footwear sales for any type of footwear made on a shoe making last or shaped on a sole moulding foot. This point cannot be stressed strongly enough. A poor last will impart poor fitting properties to the footwear, thus limiting the number of potential customers who will find the shoe to have acceptable fitting properties (Wilson and Weston 2008).

Good fitting properties also provide the foundation for comfort; fit being the number one comfort factor. Building in shock absorption underfoot or using breathable upper materials, for example, will not turn a poor fitting shoe into a comfortable one. If the shoe is too narrow or there is inadequate depth for the little toe, there will be discomfort felt before the end of the day, even if it is not apparent when the footwear is first put on.

The last, however, is not solely responsible for determining footwear-fitting properties. The characteristics of the upper materials and components, pattern design, and shoemaking processes such as lasting and heat setting will all influence the fit properties of the footwear once slipped from the last. However, getting the last design right is the critical starting point to optimize fit, comfort, sales and customer satisfaction.
1.9.2 What is a last?

Firstly, it is not a model of the human foot. A shoe made to the exact shape and size of the foot would have very poor fit characteristics and be insecure to wear. A women's court shoe (pump), for instance, would not stay on the foot if designed this way - the wearer would walk straight out of the shoe. A last is, therefore, a special shape designed to comfortably accommodate the foot shape, whilst exerting some pressure in specific areas of the shoe to ensure that it will stay on the foot, thus enabling the shoe to function correctly in wear.

When walking, the foot changes shape and size during weight bearing and forefoot flexing. Therefore, last design also has to accommodate this dynamic foot shape. How the correct standard of fit and accommodation of the changing shape of the foot is achieved depends on the footwear style. The court shoe mentioned above relies almost entirely on a tight standard of fit to keep the shoe literally clamped onto the foot. A man's slip-on shoe, however, can have a much more generous standard of fit (lower pressures) as the closed upper prevents the wearer walking out of the shoe. The elastic gusset of the slip-on also helps to moderate the pressures generated when the foot flexes.

The demands of fashion place further restrictions on the last designer who has to find a compromise between fashion and fit, whilst still trying to accommodate the largest number of potential customers possible. If a very sleek style or very pointed toe shape is required, it will be much more difficult to accommodate the broader foot, a foot with well-splayed toes or one with toe ailments such as bunions and calluses.
1.9.3 Principle of Last Assessment

The principle behind the system for assessing the potential fitting properties of lasts is, in effect, to plot the average foot shape onto the last profile and plan shape. In practice, what this means is that we measure certain key dimensions of the last and compare the results against the last dimension guidelines. The difference between the results and the guidelines then provides a measure of how well the last will accommodate the average foot. The system has been built on research over many years into the relationship between foot shape, last shape and the fit of the resulting shoe.

The last assessment method is a complex procedure involving three main tasks:

- Locating where to take measurements on the last
- Taking the measurements
- Comparing results against the appropriate SATRA guidelines.

The main parameters measured are:

- Effective last length
- Big and little toe depth
- 70° joint width
- Joint and instep girths

Most of the measurements are made using a special last assessment jig. This is used to hold the last in the correct orientation and pitch (taking account of heel height and toe spring) while locating the measurement points - such as big toe position and instep point - and to make many of the
measurements. A pair of digital vernier calipers is also used along with a flexible tape measure.

The following explains some of the measurements are made and illustrates the intricacy of the procedures.

1.9.4 Effective last Length and Toe Depths

The effective last length is defined as the straight-line length from the back of the last to the effective toe end of the last with the last correctly orientated. The effective end of the last is the position near to the toe end beyond which the last is too narrow or shallow to accommodate the toes, allowing for how they move forward when the foot flexes during walking.

Using reference data tables derived from foot dimension survey information, the jig is used to locale both the big and little toe end positions on the last. The Vernier Calipers are then used to measure the depth of the last at these points.

1.9.5 Girth Measurements

The girth measurements are made using a narrow flexible tape measure wrapped around the last at carefully specified locations. The joint girth is measured at the inside joint position and the instep girth measured at the instep point position. These two anatomically-defined positions are found on the last using the last assessment jig again and further reference to data tables.

The tape is placed at each position and laid on the last surface so as to follow a unique path called the 'continuous geodesic'. This is the line followed by the tape when it lies flat at all points on the last and returns to its starting point, and on a second circuit follows exactly the same line. This
method of girth measurement provides a unique and reproducible value for each last.

It should be noted that last manufacturers usually add raised marker points on both the inside and outside joints and a central position on the cone of the last to mark a joint girth. The position of these markers however, varies from one last manufacturer to another. They are used only within the last manufacturing process as a quality-control device to determine if the correct girth volume has been achieved from size to size within a given range.

1.9.6 Joint-Girth Ratio

An additional, and very useful measure to assess the fitting properties of a last in the forepart, is the 'joint girth ratio'.

This is calculated by dividing the joint width by the joint girth value and multiplying by 100 to express the ratio as a percentage. The 70° joint width is measured.

The joint girth ratio provides a simple means by which the cross-sectional shape of the last can be expressed. The target value for optimum fit is approximately 39 per cent (a ratio of 0.39:1), but varies a little from this value depending on wearer gender and shoe style.

1.9.7 Insock Allowance

The last assessment procedure also takes into careful consideration the thickness of the intended insock to be inserted into the shoe after shoemaking. Identifying the correct lasting allowance for insock thickness is a critical point often overlooked or compromised at a later time when the insock specification is changed.
Likewise, the last assessment procedure also takes account of whether a model last being assessed will have metal sole plates added to the final shoemaking lasts, increasing the shoe volume.

### 1.9.8 Last guidelines

There are a number of different sets of last guidelines covering men's, women's and children's footwear. Each sets out the ideal last dimensions to achieve good fit for an intended market. As suggested above, however, compromises are often made for fashion or for the requirements of specific end-uses, such as sports footwear. In these circumstances, the guidelines then provide the footwear manufacturer with a sound basis to enable a commercial decision to be made on the likely acceptance of the last in the marketplace.

A periodic review of last dimensions is recommended to check for drift in standards. Most last designs are based on historical and empirical data; new lasts are produced by modifying or adapting previously-used lasts as fashions change. Over time, therefore, there is a risk that last dimensions may drift away from the ideal, resulting in diminished fitting properties and lost sales.

### 1.9.9 Last Grading

If all feet were the same size and shape, the shoemaker's job would be so very much easier. For any style of footwear only one size and shape of last would be needed and, as the target foot would be well understood, it would be possible to design the last to give footwear that fitted extremely well.
In the real world, as we all know, the shoemaker has to contend with the fact that feet vary widely in size. To properly fit most of the population, a number of different sizes of footwear and, therefore, of lasts are needed.

The process by which different last sizes are established is termed 'last grading'. Grading may be carried out in several ways, with 'arithmetic' and 'geometric' grading being the two best-known systems. Whichever system is used, the aim is always the same - to ensure that the last size range provides footwear that fits as many of the target customers as possible with the minimum number of size steps in the range (Wilson and Weston 2008).

A grading system is, in effect, a pair of rules. The first rule defines the method by which the size differences are established, and the second rule defines the sizes of these differences. The arithmetic and geometric systems both have the same starting point: the model last, typically the middle size of the range of lasts to be produced. Both scale up from the model last for the larger lasts and scale down for the smaller ones. So, how do arithmetic and geometric grading systems differ?

We will consider the last length first. With arithmetic grading, the difference in last length from size to size is constant - for every size increase from the model a fixed amount is added to the length, and for every size decrease from the model the same fixed amount is subtracted. With geometric grading, the amount added to the length is not constant but is varies in proportion to the last length - for every size increase from the model, the length is increased by a fixed percentage and for every size decrease from the model it is decreased by the same fixed percentage.
The same approach is taken with the joint girth (Figure 1.12). Arithmetic grading results in constant differences between sizes; geometric grading results in proportional changes. How do the systems work in practice?

It is common in both the UK and USA to grade lasts arithmetically. For each increase in size, the last length grows by 1/3 inch (8.47mm) and the joint girth by 1/4 inch (6.35mm). This means that the proportions of the last differ slightly from size to size. In effect, the last grows at a lower rate in terms of girth than it does in length, so that the larger lasts are slimmer in relation to their length than the smaller lasts.

With geometric grading, if - as in the system introduced many years ago by the United Shoe Machinery Company - the same percentage increase is applied to the last length and girth, the proportions of the last remain unchanged from size to size. (This would not be the case if different percentage values were used for length and width). This means that the actual difference between adjacent sizes at the top end of the range is greater than it is for smaller sizes. However, by setting the increase at 3 per cent, the
differences in dimensions between lasts graded by the two systems are minimised. Table 1.4 shows typical effects.

**Table 1.4 Comparison of results of Arithmetic and Geometric Grading**

<table>
<thead>
<tr>
<th>UK Size</th>
<th>Arithmetic Grading</th>
<th>Geometric Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length</td>
<td>Joint Girth</td>
</tr>
<tr>
<td>5</td>
<td>262.6</td>
<td>227.0</td>
</tr>
<tr>
<td>6</td>
<td>271.1</td>
<td>233.3</td>
</tr>
<tr>
<td>7</td>
<td>279.5</td>
<td>239.7</td>
</tr>
<tr>
<td>8</td>
<td>288.0</td>
<td>246.0</td>
</tr>
<tr>
<td>9</td>
<td>296.5</td>
<td>252.4</td>
</tr>
<tr>
<td>10</td>
<td>304.9</td>
<td>258.7</td>
</tr>
<tr>
<td>11</td>
<td>313.4</td>
<td>265.1</td>
</tr>
<tr>
<td>12</td>
<td>321.9</td>
<td>271.4</td>
</tr>
</tbody>
</table>

The Paris Point system (which is also known as the Continental system), like the UK and USA systems, is arithmetic, but uses smaller last length and joint girth intervals. These are 2/3 cm (6.67mm) and 1/2 cm (5mm) respectively, and are in the same proportion as the intervals used in the UK and USA systems.

**1.9.10 Fittings**

Because there are fat feet and thin feet, it is necessary to make lasts especially for them. The dimensions of these lasts are also produced by grading. In the UK and USA systems, for a single increase in width fitting the girth is increased by 3/16 inch (4.76mm) for smaller sizes (that is, for
children's feet up to 169mm long) and 1/4 inch (6.35mm) for all larger sizes. The same values are used for decreases in girth. With geometric grading a change of 3 per cent in joint girth for each change in width grade is employed.

In the Paris Point or Continental system, the change in girth for a single width fitting is 5mm.

1.9.11 Which is the Better System?

Small feet and large feet have different proportions. In general, large feet are narrower in relation to their length than small feet (Figure 1.13).

![Graph showing joint girth/length ratio for a range of foot sizes](image)

**Figure 1.13 Decrease in joint girth/length ratio as foot size increases**

Arithmetic grading, unlike geometric grading, produces large lasts that are narrower in relation to their length than small ones, and so can be considered to have an advantage. However, an investigation carried out several years ago in which a last was graded in different ways, showed that arithmetic and geometric grading gave acceptable results in terms of producing footwear that fitted as many of the target wearers as possible. This suggests that the shape of lasts produced using the arithmetic system changing
from size to size (in a similar way to the shape of feet) is not a critical factor. The key critical factor is ensuring that the dimensions of the model last are correct, not the choice of method of scaling up and down from the model.

Geometric grading was developed in the days when it was predicted that the future of the footwear industry lay in automation. At that time, it was believed that arithmetic grading was a hindrance to the introduction of automatic systems. Geometric grading enables the last holding position (the thimble hole) to be standardized, regardless of the last size which, among other benefits, aids location and movement of the last along the track.

So far, the predictions regarding the impact of automation of the footwear industry have not been fulfilled - largely because of the impact of low labour costs in the Far East - which helps explain why geometric grading has not been more widely adopted. If there was renewed impetus for automation, would this favour geometric grading? Probably not, as technology has moved on considerably since the early days of automation and, almost certainly, would be capable of successfully incorporating arithmetic grading.

To summarize: there is no driving force for a change from arithmetic grading to geometric and, as there is no perceptible advantage in doing so, arithmetic grading will continue to be the predominant system.

1.9.12 Last Standardization

Each component of a shoe made on a last has to be of a suitable size for that last. When every dimension of a last changes from size to size, the shoemaker has to produce suitably-sized components for each size. However, certain features of a last may be kept constant over a limited range of sizes -
termed a group - without significantly affecting the fitting characteristics of the footwear. This process is known as 'standardization'.

Standardization is usually confined to the back of the last behind the joint line. This is where its greatest potential lies. For example, usually one waist curve is satisfactory for three or four heel heights so that, for a range of heel heights up to 80mm, six waist curves will suffice.

Some further economies can be made when lasts in other sizes are produced, it is possible to group the seats over a range of sizes. This enables one heel to be used on several sizes (up to four half size intervals) which gives a significant saving in heel mould production.

The principle of grouping lasts may also be used in a process by which the shape of lasts is altered to adjust toe spring and heel height across the size range, termed 'semi co-ordination.'

1.9.13 Lasts: Satisfying the Demands of the Footwear Industry

Most types of footwear have to be produced on a last or mould to ensure that the end product has the shape and dimensions intended by the shoemaker. Consequently, the last plays a major part in creating the fashion appeal and fit of the resultant footwear.

The overall responsibility for the footwear's shape and dimensions lies with the shoe manufacturer or retailer who brings the product to market. However, the last manufacturer also makes a major contribution to achieving the end result. The last manufacturer must produce an accurate, durable product that can satisfy the demands of the shoemaking process (Weston and Wilson 2009).
Although foot shaped, a last is not an exact copy of the foot. Its shape is dictated by factors in the final footwear such as fit and comfort or, for fashion shoes, features demanded by the designer - for example, a pointed toe. The development of the model last is usually done by the last maker in consultation with the shoe manufacturer or retailer. The process requires considerable skill and accounts for a large proportion of the cost of producing a new last.

It is at the modelling stage that decisions are made on size range and grading intervals. Good communication between the last manufacturer and the shoemaker is important, so that aspects which have a potential effect on the fitting properties of the footwear (such as whether or not a foot bed is to be inserted) can be taken into account.

1.9.14 Last Materials

Traditionally, lasts were made from wood. Today nearly all lasts used for conventional shoemaking – i.e. where no significant heating above 150°C / 302°F occurs - are made from polyethylene (polythene).

Polyethylene is a thermoplastic polymer and has the following advantages:

- Stability - shape and dimension unaffected by normal shoemaking temperatures and humidity
- Strength - shape and dimension unaffected by the mechanical operations in shoemaking
- Surface - smooth and low friction to enable the upper to be adjusted during lasting and to help in last slipping
• Manufacture - easily shaped by turning

• Recyclable - both the waste produced when the last is produced and the last itself may be recycled.

The grade of the polyethylene used for the last is vitally important. There are three main grades of polyethylene based on density. High-density grades are tougher, less liable to distortion and breakage during use than lower-density grades and, for these reasons, are the preferred choice for lasts. High-density grades, however, are more difficult to process, requiring closer control of moulding conditions. SATRA TM130 provides a method for assessing the suitability of different plastics for use as last materials. The procedure incorporates a simple three-point breaking test and may be used to determine the rigidity and breaking load of the material.

The other important material used in the construction of lasts is Aluminium. This can be cast or milled, and is commonly used where high temperatures are employed in the curing or moulding processes of shoemaking - for example, in the production of vulcanised and injection-moulded footwear.

1.9.15 Manufacture of Production Lasts

The manufacture of polyethylene lasts begins with the production of a wooden model, followed by the making of a block from which the last is shaped.

Production of the block: The polyethylene is supplied in the form of granules. These are formed into a block by heating and moulding under low pressure. The block is converted into the desired shape in two stages, rough turning and fine turning.
It is common to have a mixture of virgin material with a controlled percentage of recycled polyethylene (this may be reclaimed from waste generated during the process of the last manufacturing or from redundant lasts). The screw speed of the moulding machine needs to be carefully controlled to ensure the materials being moulded are correctly mixed.

Control of the temperatures at moulding and during the all-important cooling phase is critical to prevent voids and build-up of stresses which, if present, will result in subsequent weaknesses and potential breakages. After cooling, the blocks are trimmed at both ends to provide faces to enable the block to be located and held in a lathe.

1.9.16 Rough Turning and Hinge Insertion

The aim of rough turning is to remove excess material as quickly as possible, and thereby produce a slightly oversized version of the required final shape. Precision is not a key consideration at this stage and the only purpose of the dimensional check made after rough turning is to ensure that the part-formed lasts are large enough to accommodate the finer turning.

Prior to the introduction of computer-aided technology, these lathes enabled two or three pairs of last to be copied from one physical model. This process involves mounting the model and a number of polyethylene blocks on the copy lathe. A tracer or dummy wheel moves over the surface of the model, and simultaneously controls the movement of a number of high-speed cutters which shape each block into the rough turned state.

The excess material remaining at the heel and toe of the roughed lasts form extensions that are termed 'dogs'.

After rough-turning, the hinge mechanism is inserted. Firstly, hinge cuts and slots are made, with the rough block being held by the heel and toe dogs. In a two-part operation, the V slot (or ‘vent’) is cut out and the hinge pin holes are drilled. The rough last is cut into two pieces and the slots made for the hinge final assembly.

### 1.9.17 Second Turning (fine turning)

The second turn involves the roughed hinged last being returned to the copy lathe and located by its heel and toe dogs to ensure the turning axis is correct. The second turning is made more slowly to produce the last in its required dimensions. It is this critical operation that has most effect on the final shape of the last and, ultimately, the shoes that are made from it. Care needs to be taken to ensure that the lathe is correctly set to give the required length and girth grade.

### 1.9.18 Removal of Toe and Heel Dogs

First the toe dog is cut off, and the last bottom in this region is planed to shape using the toe end of bottom patterns (which have previously been cut to the shape of the model) as a guide to ensure that toe shape is correct. The heel dog is then removed. Most of the excess material is cut away and the remainder is removed in two operations. The first consists of cutting the heel curve in one plane using a template to ensure that the correct line is achieved. The edges produced by the operation are then gently rounded using an abrasive disc to produce the correct shape. The overall length of the last is finally measured using a last makers size stick to confirm the last dimensions are correct for length for the marked size. If not within last-making tolerance the last is discarded and replaced.
1.9.19  **Bottom Plating**

In those cases where the shoe manufacturing process necessitates reinforcement of the last bottom, the next stage is to attach thin metal plates. Last bottom plates were necessary in the days when tacks were used to hold the upper to the insole. Their purpose was to turn the tips of the tacks so that they clenched onto the insole. The use of tacks in lasting is now rare and consequently, the demand for plated lasts is greatly reduced.

1.9.20  **Top Plane and Socket Insertion**

The next operation is machining of the top plane - usually with a milling machine - to produce the required back height. After the top plane has been machined and the hole drilled, the socket or thimble is fitted. During footwear manufacture, the last may need to be located and held; a hole with a thimble inserted providing a means of doing this. The back height, top plane orientation and position of the thimble must be carefully controlled.

1.9.21  **The Final Operations**

The last is stamped with the relevant references and checked to confirm its dimensions are accurate for the marked size in length as well as the joint and girth. Lasts may include graded back height and vamp marks on the finished last to assist shoemakers in lasting operations.

1.9.22  **Co-ordination**

Unless an adjustment is made, it is inevitable that the larger lasts graded from the model size will have greater heel heights and toe springs than the model last, and the smaller lasts will have tower heel heights and toe springs. Depending on the requirements of the shoemaker, an additional operation to counteract this effect may be introduced. This procedure, termed
'co-ordination', is used to maintain a constant heel height and toe spring across the size range.

Traditionally, co-ordination is carried out by adjusting the shape of the basic last by cutting and wedging to produce a sub-model. Typically, lasts every 1 1/2 sizes each side of the model size are co-ordinated in this way.

Co-ordination results in smaller sizes of shoes having higher heels in relation to their length than larger sizes, and more pronounced waist curves. These effects bring disadvantages - for example, the fit of shoes made on the smaller sizes of lasts may be adversely affected, particularly with higher heeled styles, because the 'cranking' (waist shape) of the shoe may be so extreme that the foot cannot conform properly to it. Furthermore, co-ordination results in the larger sizes looking different from the smaller size, which compromises the normal aim of a designer to create a range in which each size looks as much the same as possible.

When no adjustments are made, the process is known as 'straight grading'. Currently, straight grading is more commonly used than co-ordination.

1.9.23 Newer Methods of Producing Lasts

Computer Aided Design (CAD) was introduced into shoemaking as early as the 1970s. It was then primarily used for grading rather than design purposes. CAD has now evolved into a design tool used in the development of lasts, as well as for footwear itself. There are a number of factors that have encouraged this move, including:

- Availability of more powerful hardware (such as digitizers) at more affordable prices
Major improvements in graphics capabilities and interconnectivity

Introduction of more user-friendly software with lower skill requirements.

The introduction of CAD has enabled semi-skilled operatives to construct 3D last forms from a library of last shapes - obtained originally by digitally scanning real lasts - and to engineer or manipulate the last section on a computer screen rather than working with a physical object.

The ability to blend toe shapes, foreparts and backparts with different heel heights on a CAD system, and to do this rapidly, is an advantage over more traditional hand-modelling methods. The alignment between the bottom plane and the upper surface of the last can be adjusted, as can toe spring and back height.

Once the 3D form has been constructed and the correct last curvatures achieved, the data can be used in the development of upper patterns, bottom components and other tooling. Modules are also available to compare different lasts, to analyze deviations and perform shape analysis.

Having defined the last shape, it can be graded and the data passed to a numerically controlled (NC) last-machining system. The great benefit here is that the design and manufacturing processes can be undertaken in different parts of the world. For example, last design may be undertaken in the USA, but the lasts themselves may be produced in China - close to the manufacturing plant.

Current last turning equipment can produce lasts to a high degree of accuracy. However, manual operations such as cutting, hinging and the
removal of the heel and toe dogs can reduce the accuracy, although it is still possible to work to a high degree of precision with the last, as well as for positioning location devices used, for example, in automated milling last construction.

With traditional methods of producing lasts, after fine turning, the toe and heel dogs are removed by hand. The introduction of toe and heel milling machines has given a higher degree of accuracy to the finished product.

Undoubtedly, digitized last data is being used to control all stages of last production leading to greater accuracy in turning and finishing of the final last, and reduce the need for further processing.

1.9.24 Durability in Manufacture

In footwear production, lasts are repeatedly subjected to high levels of strain, such as in the sole attaching process. Lasts may be used several times each day over a period of several months or even years. Lasts are designed to withstand these rigours but as with any precision tools, they need to be correctly used and treated with some degree of care. Unfortunately this is often not the case. Sole attaching presses, for example, sometimes may have their pressure set up incorrectly, and it is not uncommon to see operatives throw lasts considerable distances into storage bins.

In most countries, high-density polythene is now used for last production, but metal (particularly in the Far East) is still used in some areas. Aluminium may be able to withstand greater heat than polyethylene, but care is still needed during handling.
To help shoemakers use their lasts in the most efficient manner, it is worth remembering the following:

- **Material/design** - Where extreme damage is encountered, it may be traced to the use of a low-quality plastic. The high-density polythene used by major manufacturers rarely gives problems of this type unless the last design is extreme or if sites where strains may be concentrated are inadvertently introduced. This could, for example, occur if cutting to accommodate a toe plate extends too far into the plastic.

- **Damage to the hinge system** - This can result from excessive pressure at sole attaching. The problem may be due to incorrect pressure distribution, which creates high-localized forces. Typically, the damage caused is the loosening and overstraining of the hinging system.

- **Damage to bottom plate** - This may also be associated with the sole pressing operation. When overstrained on lasts which have full plates, the back and forepart plates can touch, causing one to be pushed up, thus exposing sharp edges which can damage the footwear.

- **Loosening of the thimble and damage to top plain of last** - Another common area of damage is the top of the last near to the thimble. This may be limited to distortion of the plastic or, in extreme cases, is sufficiently severe that the thimble itself.

### 1.9.25 Hinging Systems

On completion of the footwear manufacturing process, the last has to be removed from the footwear. During removal, the relatively wide back
part swells of the last have to pass through the often narrow topline of the shoe. Inevitably, this can result in considerable distortion and stretching of the shoe upper and, with highly structured styles, this can result in damage to the footwear. Most lasts are hinged so that in the act of 'breaking' the last at slipping, the overall length of the last shortens and releases the tension on the upper's topline.

There are a number of different ways of doing this:

- **Link hinges** - the most widely used system in Europe and North America. A ‘C’ shaped spring, held in place by two pins, is used to hold the last in either its closed or broken position. The interface between the back and forepart of the last is cut to provide a pivot, so that the last can be shortened to aid removal. The spring is inserted always be present whether the last is broken or not.

- **Reverse cut hinge** - not actually a hinge, but a series of linkages that hold the last in its closed position and enable the back part to rotate, thus shortening the last when broken. Each link has a hole in one end and a slot in the other, and a slightly distorted ‘C’ spring. When the last is closed, the two pins holding each link are at their maximum distance apart, with the hinge under tension.

- **Backward vertical hinges** - a variant of the reverse cut in which the backpart rotates downwards relative to the forepart.

- **Scoop block** - this consists of a section of the cone that can be released from the last. It is only suitable for low heel styles and, unlike the other hinging systems, the actual length of the last does not shorten.
The assessment of lasts requires knowledge of which dimensions should be measured and two key skills: the ability to locate the measuring positions, and the ability to take the measurements accurately.

Typically, the following dimensions are measured:

- Effective length
- Joint girth
- Joint girth ratio
- 70° joint width
- Big toe position and depth
- Little toe width and depth

1.9.26 Accuracy of Lasts

The difference between half sizes of footwear in the UK/USA sizing system is only 1/6 in. (4.23mm) in length, 1/8 in. (3.18mm) in joint girth and 1/24 in. (1.06mm) in ball width. It is clear, therefore, that a high level of accuracy is essential in the dimensions and shape of lasts. This becomes even more important with the increasing automation of the shoe manufacturing process, which can only be effective if all components fit. and is particularly true when the making last is also used as the moulding foot.

Lasts from good quality manufacturers are normally well within the accuracy needed by shoe manufacturers. Typically the following standards are achieved:
1.10 **TECHNIQUES FOR MASS SURVEYS**

1.10.1 **Fitting, Foot Surveys and Size Conversions**

Good fit is the fundamental prerequisite for sales. It does not matter whose brand name is on a product or what cutting edge technology and performance benefits might be designed into the product – if the shoe does not fit, it will not sell. Furthermore, if the fitting characteristics are not aimed at accommodating a range of foot dimensions centred on the average values of the target population or market (customer sector), maximum sales will not be achieved.

The key elements in securing maximum potential sales of footwear are:

- Knowing the foot dimensions of the target market
- Identifying a suitable last shape to satisfy that market
- Making prototype sample footwear, then checking and revising until good fit is confirmed
- Carefully grading out from the sample size to check fit across the full size range
- Making production samples, and checking that bulk production is the same as the samples
- Correctly size marking the product so customers can easily identify their size.
The whole process should be customer focused. The goal is customer satisfaction, building brand confidence, customer loyalty and repeat business (Wilson 2013).

### 1.10.2 Changing Times

The footwear industry has changed significantly over the last 20 years. The supply chain is dispersed around the globe, with the designer, product developer, last developer, last maker, upper assembler, shoemaker, sourcing agent and retailer all potentially being located in different countries. Electronic communication today is fast, but not necessarily as effective as we might like to think. Technical instructions and specifications can be difficult to translate into other languages, and customs and practices vary between countries and cultures. It is difficult to get a consistent approach and to coordinate all parts of the chain.

There is a skills shortage when it comes to fitting, even in large companies. Lack of knowledge and experience makes accurate communication all the more important. There may be knowledgeable individuals in the supply chain, but they may be isolated from each other. Some companies apparently consider fitting too difficult to even tackle, and so ignore the importance of the subject.

There is greater time pressure on product development, with less time to fit shoes and make corrections or improvements. Consequently, more compromises are likely to be accepted with the final product.

### 1.10.3 Retailing in the 21st Century

Retailing has also changed. Markets are becoming more global and, therefore, globally diverse. However, many manufacturers would like to sell the same product everywhere, thereby minimising the number of product
variants necessary to satisfy multiple markets. This presents a dilemma – we know there are ethnic differences in foot shape in different parts of the world so, ideally, lasts and footwear should have different dimensions for different geographic locations. Doing this will, of course, incur additional production costs. It must also be remembered that we have many multicultural societies today, which raises the question of whether shoe stores should have shelves for different foot types. Perhaps a return to wider availability of a range of width fittings is desirable – certainly for the customer.

Research and Development is underway to make mass customisation a viable and low-cost option, in order to give everyone ultimate satisfaction. Bespoke footwear previously has only been within the reach of the wealthy customer or those with particular orthopaedic needs. Mass customisation aims to enable any customers’ feet to be scanned digitally to the internet and downloaded into a factory where the customer’s specification can be turned into a pair of shoes for mailing to the customer within just a few days. This is still an ambitious goal, and even traditional bespoke footwear may take a couple of fittings to get it right.

However, we have seen that internet footwear sales have grown rapidly. Correct and meaningful size marking (discussed later in this article) is, therefore, increasingly more important to help make customers’ buying decisions as easy as possible. There is a considerable amount of confusing and conflicting information on sizing for customers to read on websites, and a significant variation in interpretation of size scales between retailers.

Reports suggest that poor fit is the cause of 50-90 per cent of all internet purchase returns. Up to half of all customers will deliberately order two or more sizes of a given style to make sure they receive a pair that fits,
knowing that the others can usually be returned free of charge. These figures will almost certainly exaggerate the situation because, for example, customers may use poor fit as an easy excuse to return shoes for other reasons. Nevertheless, it is clear that fit is a significant factor and each return carries a cost to the retailer.

1.10.4 **The Principles of Good Fit versus Fashion**

What is good- or well-fitting footwear? Clearly, as previously suggested, it is a shoe (or boot, or sandal) that is matched to the shape and dimensions of the customer’s foot.

In addition, a good-fitting shoe should facilitate full normal foot function in wear – whether that involves walking, running or jumping – without causing restriction or discomfort. It should be conducive to maintaining foot health and without adversely affecting gait and movement in a way that might cause other lower limb or back problems.

There are many foot health issues to consider and ailments to avoid that can be caused by poor fit, such as blisters, calluses, bunions, tendonitis and instep pain. Children’s foot problems caused by ill-fitting shoes worn while their feet are still developing and particularly vulnerable, are likely to stay with them throughout their life.

Summarized below (Table 1.5) is a list of the main criteria that define the ideal fitting shoe, but for a variety of reasons many shoes do not meet these criteria. The practical or commercial reality is, therefore, that very often the aim of fit assessment is to optimise design and minimise the risk of discomfort and foot health problems occurring.
Table 1.5 The Principles of Good Fit

- Match the size and proportions of customers’ feet in the intended market
- Allow the foot to function normally in the activities and applications for which the footwear is designed
- Promote foot health and not cause any discomfort
- Have the correct shape and accommodation for the toes
- Eliminate pressure which causes distortion of the foot or toes
- In children’s shoes, there should be adequate space for growth
- There should be a fastening system which holds the foot securely in the correct position and alignment in the shoe
- The fastening system should be adjustable to accommodate a range of individual foot shapes
- The upper should have no hard seams or exert high pressure points on any part of the foot to cause discomfort or rubbing
- The shoe should have a low, broad heel to provide a stable platform
- The bottom construction should be cushioning and flexible, bending in the correct position with respect to the joint of the foot
- Firm arch supports are best avoided, as these can cause undue pressure on this sensitive part of the foot
- Footwear should be designed, constructed and manufactured from materials and to standards that ensure fitting and comfort properties are maintained throughout the product’s lifetime.

It has to be accepted that some compromises on fit will have to be made. Styles that do not incorporate a fastening system cannot be self-adjusted to an individual foot shape. The women’s court (pump) shoe is an extreme instance – it is only prevented from falling off the foot when walking by clamping the foot tightly between the heel counter and forepart vamp. This
is clearly not ideal for comfort or foot health, but is tolerated for fashion. At the other extreme, there is the Wellington boot, which is also without a fastening system but is a loose fit on the foot.

Of course, some wearers must accept that they have a foot shape that lies outside the normal population range that is accommodated by mass-production footwear. Many people will also need to compromise fit on one foot, where they have a significant difference between left and right feet.

However, a line does have to be drawn at some point. For example, SATRA would never condone small children wearing high heel court (pump) shoes.

1.10.5 Basis of Fit Assessment

The first opportunity to examine potential fitting properties is during last development, when a ‘last assessment’ can be undertaken. The dimensions of the last are compared with the dimensions of the foot it is required to fit, and the differences are evaluated as an indication of quality of fit.

Of course, good last design alone will not guarantee good footwear fit, although bad last design will almost certainly damage sales. Choice of shoemaking materials, construction method and conditions within the shoemaking process itself will all influence the eventual fitting properties of the footwear. Two different shoe styles made on the same last, or the same style made on different production lines, may well have different fitting characteristics. So it is important to assess sample footwear for fit at the earliest opportunity, and again later, when the product moves from the sample room to bulk production.
The fitting process involves putting feet in the footwear, which sounds simple enough, but it has to be done carefully and systematically to obtain meaningful, accurate and reliable results. The SATRA TP4 test protocol sets out a structured approach to do this. Training and practice, however, are required to achieve a good standard of competency.

The key to fitting during product development is to remember that the aim is not to determine how well footwear fits an individual person, but to predict how the shoe will fit the normal population. By ‘normal population’, we mean the typical or average range of foot dimensions and foot shapes seen within the intended market.

To do this accurately, at least five or six subjects per size should be used, with their feet being measured each time so that they can be compared with the target values. It is necessary to exclude subjects who have foot health problems, or unusual foot shapes or defects (such as flat feet or claw toes), which make them atypical of the normal population.

1.10.6 Key Points of Fit Assessment

Assessing shoe length means checking that there is adequate toe allowance or space in front of the longest toe to accommodate the dynamic movement of the foot within the footwear during walking. A toe allowance is required, because during each walking step the foot elongates due to loading (bodyweight) and flexing action. For most adult footwear, a toe allowance of 8-10 mm is desirable, although this will vary slightly depending on footwear style and application. In addition, footwear having a narrow or pointed toe style requires extra length to include a design allowance at the extreme end of the shoe where the wearer’s toes cannot enter without undue pressure and discomfort.
Assessing forepart width and depth (volume) is more difficult, and requires greater experience. The acceptable amount of volume also depends very much on the type of footwear being assessed. There is little scope to compromise on the length, but width or volume can range in absolute terms from close (fashion shoes) to generous (comfort or walking shoes) while still being considered acceptable for the given footwear type and end use.

Having examined these two key aspects, the assessors then should go on to check all other areas of the footwear, including the functioning of the fastening system, if present, and back part shape.

Once the assessment is complete on all subjects, an overview of the results is then made, and recommendations given for corrections or minor amendments as necessary.

1.10.7 Foot Dimensions and Surveys

As stated, the basis of fit assessment is a knowledge of the average foot dimensions of the target market. However, there is a need to update and broaden the database. Technology has also moved on – previous data was collected using the stick and tape approach, which is still perfectly satisfactory and effective today for undertaking fit assessments, but 3-D digital scanning, is so much more powerful as summarized below:

1.10.8 3D Scanning

The foot scanners employed utilise eight laser light sources and detectors that surround the foot. These track along the length of the foot to build up a highly detailed three-dimensional surface image. The electronic image of the anatomical foot shape comprises thousands of discrete surface elements, each less than one millimetre square. Three anatomical reference
points are then located – situated at the back of the heel, the medial (inside) metatarsal joint and the lateral (outside) metatarsal joint. From these three ‘base’ points, other important anatomical reference points are identified, all being defined by their spatial relationship to the base points.

Using the x, y and z coordinates of each point, the linear distance between any selected pairs of points can be calculated. This can determine, for example, measurements of foot length or instep girth. The advantage of electronic surface scan data collection is that the scan can be re-analysed at any time, and new data points assigned for additional measurements. The actual foot scanning operation takes only a few seconds and the computer data processing even less time.

It should be remembered, however, that the foot has a variable size and shape. Over the course of a day, the foot will swell and contract in size, depending on the activity and body temperature of the subject. How the foot is placed into the scanner and the bodyweight is applied will determine how the foot shape changes under load. So, while the foot dimensions should be recorded as carefully and accurately as possible, there will be an associated uncertainty in the measurement.

The three key data points are foot length, joint and instep girth. However, once a foot scan is captured, the number of additional measurements that can be made is almost limitless. For example, the instep or arch height can be recorded to complement the instep girth information. Likewise, big and little toe depths give greater characterisation of the joint girth measurement. At the press of a key, a list of, for instance, 30 parameter values can be instantly printed out.

Surveys are time-consuming and expensive to carry out, due to the need to collect thousands of data points in order to cover the various footwear
markets – gender, age, geographic region, ethnicity and so on – and gain statistical confidence in the results. As an example, Figure 1.14 shows results for nearly 300 children, collected to begin an investigation into the growth rate of boys’ and girls’ feet.

![Figure 1.14 Growth rate of boys’ and girls’ feet](image)

1.11 DIFFERENCES BETWEEN SHOE SIZE SYSTEMS

The UK size system is the oldest currently used system – it can be traced back to Anglo-Saxon times, when lengths were measured in barleycorns (about one-third of an inch – approximately 8.5mm). This system was also adopted in the US but with minor changes. The European system evolved much later, and is based on the metric measurement. The Mondopoint system was then devised to try to overcome the problem of having two systems (European and UK), but effectively became a third system used extensively today in China, Japan and others parts of Asia.
There are two fundamental factors that contribute to making size conversions so difficult. Firstly, the UK and European (‘Eur’) systems were actually measures of shoe or last length, not foot length. Of course, shoes must be longer than feet in order to incorporate the toe and fashion allowances required – as discussed earlier in this article. This means that there is a variable relationship between foot length and last length, depending on the shoe style. The Mondopoint system is much simpler, as it is based specifically on foot length.

Figure 1.15 Grade increments for different sizing systems

Secondly, and most critically, the three systems – Eur, UK and Mondopoint – use different grade increments between sizes (Figure 1.15). Thus, it is impossible to give accurate size conversions using just whole, or even half size notations. If a range of nine Eur lasts are produced, such as sizes 35 to 43, but the retailer wishes to sell shoes marked in UK sizes, he either needs to include two UK half sizes, perhaps 4½ and 8½, or drop two lasts – maybe 37 and 42. If the latter option is taken, at two points in the range
there becomes a big jump for the customer of approximately 13mm between successive sizes. Similar decisions have to be made when working between any two of the three sizing systems.

1.11.1 Size conversion chart

The foot length associated with UK sizes was established several decades ago, but the same has apparently not been done for the European system. European companies and organisations, are still thinking mainly in terms of last length rather than foot length, and there are different approaches to calculating toe allowances.

Overall however, it seems that a technically more accurate conversion is obtained by dropping the Eur sizes in the size conversion table by approximately a half Eur size. Table 1.6 show how this works out for a selected range of sizes, although we believe the same applies across the full range of children and adult sizes. Columns 2 to 6 show long-standing conversions set against foot length in column 1. Then, in column 7 on the right, we have added the proposed new Eur size conversions.

Eur size-marked shoes have often come up slightly long against their equivalent UK size. It was found that although, for example, UK size 4 is usually taken as equivalent to a Eur 37 and women might find both UK 4 and Eur 37 shoes acceptable, a better correlation is found between Eur 37 and UK 4½, or UK 4 and Eur 36½ shoe if available.
Incidentally, some manufacturers have effectively redefined the UK system by using the Eur system as the basis of conversion. This approach changes the UK sizing and results in their UK sizes fitting slightly longer feet than we would accept. For instance, UK 9 is equated to Eur 43½, shifting the size conversion in the opposite direction to that which we are proposing.

ISO/TC137 – the International Organisation for Standardisation (ISO) committee considering international size conversions – is moving toward similar conclusions and are in process of publishing a committee draft document for examination by national standards bodies around the world for comment.
1.12 FOOT SCANS IDENTIFY KEY FITTING CRITERIA

For an item of footwear to be a commercial success, it must be comfortable to wear on the highest possible proportion of the intended market. Therefore, ensuring that the dimensions and shape of the footwear lie at the centre of the target size range is an essential part of the product development process (Weston 2010).

The human foot has a complex form determined by its internal anatomical structure (bones, tendons, ligaments, muscles and fat). The skin covering the foot can be considered as a three-dimensional canvas for the foot dimensions. This size and shape can then be transformed into a model surface to form the basis of an appropriate last, which will define the internal volume of the footwear and its shape.

1.12.1 Why Measure Feet?

Information on the shape and dimensions of the foot is of key importance in ensuring that footwear is designed to fit correctly. There are many methods of measuring feet and many different measurements that can be recorded. The most common method of measurement is using the combination of size stick and tape, although a stand-on board is also widely used.

The choice of measurement devices will depend on how the information is to be used. The former method is most suited to provide the detailed information needed to define population foot dimension statistics for the development of a last for a mass-market product. The stand-on board, or 'shoe size indicator' as it is sometimes known, is a simpler and much more practical method which is extensively used as a fitting aid in children's footwear retail outlets.
As with all physical objects, the human foot can be characterized by its dimensions. The appropriate set of measurements, processed according to established anthropometric techniques is used in the development of sizing systems. In many areas of anthropometric research and consumer surveys (for example, foot comfort), reliable and wide-ranging data collection is essential. This need has driven the development of more productive, accurate and reproducible methods to measure feet dimensions and electronic scanning devices are the result.

1.12.2 How do Scanners Work?

Today, most foot scanners employ optical techniques, using either visible or laser light sources. In general, the more sources present in the machine, the better the foot coverage and the more accurate the image. The scanner utilizes laser light sources and detectors surrounding the foot, which give a highly detailed three-dimensional image.

Due to the miniaturization of modem electronics, most of the latest generation of scanners are very much smaller than their predecessors, albeit within the constraints of having to accommodate a scanning volume of at least the lower leg and foot. Although many designs are described as 'portable', this does not mean they are easily transported and quickly brought into operation at different sites. Even such 'portable' machines require complicated dismantling and reassembly operations and, due to the fragility of the laser and detector alignment mechanisms, will necessitate lengthy recalibration procedures after transport.

There are a number of small models (some even hand-held), although the simpler the device, the longer the scanning processes may be and the quality and quantity of data may be lower.
Whatever the size and complexity of the device, all will require specialized data processing software to create, measure and manipulate the three-dimensional foot image. A computer linked to the scanning device is, therefore, essential.

1.12.3 Processing Foot Scan Data

The scanner works on the principle of capturing the anatomical foot shape electronically in discrete surface elements of less than one millimetre square. The scan is built up using these elements, and three critical triangulation points - situated at the heel, the inside metatarsal joint and the outside metatarsal joint - are then identified. From these three 'base' points, 15 other important anatomical reference points are identified, all being defined by their spatial relationship to the base points.

All these surface points are assigned three-dimensional coordinates (known as x, y, and z values), and these can be used to calculate the linear distance between any selected pairs of points. Users can select whatever data points and linear measurements are required - for example, foot length or instep girth, or assign new points of interest to their particular studies. The advantage of electronic surface scan data collection is that the scan can be reanalyzed at any time and new data points assigned for additional measurements. The actual foot scanning operation takes only a few seconds and the computer data processing even less time, although high-definition imaging may take a little longer.

Now that foot scanners are becoming more common, the technology has been developed to enable the integration of foot scanner output data into other systems, such as Computer Aided Design and Manufacturing (CAD/CAM) systems. This enables the data to be used in further applications
to suit a wide range of industry standards and manufacturing processes, including computerized last production.

1.12.4 Foot Surveys

A foot scanner provides the opportunity to gather vast amounts of data to a high accuracy on the foot dimensions of a population sample. Foot scanners can record millions of data points and potentially improve the accuracy and consistency of both foot and last measurement data.

Last ranges can be developed from this information. However, experience suggests that use of a foot scanner does not, of itself, speed up the foot measuring procedure - speed is dictated by the availability and delivery of the subjects. Nor does it de-skill the process by which the data is interpreted; expert input is still required to define the last shape that ensures footwear produced on it fits the highest possible proportion of the intended market. However, a scanner does mean that more detailed information can be produced, and in a consistent manner.

1.12.5 Mass Customization of Footwear

This is an area where there is currently considerable interest in the use of foot scanners. The idea is that information on an individual's scanned feet is used to identify key fitting criteria, so that either a standard footwear style can be selected to match his or her fitting profile, or footwear can be produced to meet these requirements. It also allows different designs and material variations on a standard style to be developed - again, to match a particular fitting profile.

This scenario involves a customer’s feet being scanned in a retail shop to provide their 'fit profile', which could be carried in credit card format.
This information could either be transmitted to a remote shoe factory for footwear of the correct style and dimensions to be produced or to choose existing styles which will give the best fit.

Last development Current scanning systems contain software that can be used to compare the three-dimensional foot data with integrated sizing tables and last library data. This will allow the footwear manufacturer to select the most compatible last for that foot, or to assist in the development of improved or customized lasts. The improved data on foot shape and shoe last dimensions also enable other footwear components to be developed or improved to maximize fit and comfort. An example of such customized components is an orthotic foot bed.

1.13 FOOT LENGTH and SHOE SIZE MARKINGS

1.13.1 Understanding Foot and Last Lengths

Consumers may get to believe they know what sizes in different scales suit them best but, in practice, they might find different sizes would suit them better. For example, many women associate size Eur 37 with UK 4, and may find in practice that shoes made to be a Eur 37 and shoes made to be a UK 4, will fit reasonably well. However, they might find a better fit if half sizes were available. The average Eur 37 foot may well be fitted better by UK4½ shoe and likewise, an average UK 4 foot would perhaps fit better in a Eur 36.5 shoe if available (Wilson 2011).

We look at some of the key measurements (Table 1.7) that last makers and shoemakers might make when developing and fitting new products. We try to show that how the measurements are made can influence the final size marking. Inconsistencies in using the different methods through the supply chain can result in errors in size marking.
Table 1.7 Different Types of Measurements

<table>
<thead>
<tr>
<th>Foot length</th>
<th>Last length</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stick and Board length</td>
<td>Stick length</td>
<td>Insole length</td>
</tr>
<tr>
<td>Weight-on/weight-off</td>
<td>Effective length</td>
<td>Out sole length</td>
</tr>
<tr>
<td>Static/dynamic</td>
<td>Bottom pattern length</td>
<td>Insock/footbed length</td>
</tr>
<tr>
<td>Sole print/effective length</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Foot length

The first thing to say about measuring the foot is that it can never be precise in the same way that a metal block or even a shoemaking last can be measured, for example. The foot has a flexible structure, an irregular shape and is covered by soft, compressible tissue. Shape and size will vary according to how the subject sits or stands, the time of day, the temperature, recent level of exercise and so on. So, while measurements should be made as carefully and accurately as possible, the results should be seen as indicative rather than exact.

The simplest, and probably most commonly used, accurate manual method of measuring foot length is the weight-on stick length. The fixed end of the device is presented to, and held gently held against, the back of the heel curve of the foot, while the 'stick' is held against the inside swell of the heel and ball of the foot. This line is known as the 'inside tangent', and can be easily replicated on lasts, moulds and insoles to give a consistent approach to length measurement. The sliding end stop is then moved up to the end of the longest toe (usually the big toe, but may be the second toe) and the foot length read off in millimetres.
When undertaking this measurement, it is important that the subject is standing head up and with feet comfortably positioned slightly apart. This ensures a correct and even pressure distribution over the heels and balls of both feet.

If feet are measured weight-off - for instance, when sitting down - it must be remembered that lower results will be obtained. This is because the foot elongates when standing as the bodyweight is loaded onto the longitudinal arch, which then tends to flatten and lengthen the foot.

Based on available and reliable data the foot measurement survey made in India led to a very important conclusion: the proportion (i.e. shape) of feet of the local population differs considerably from what is built in European and North-American shoe lasts. The main reason is the ethnic (anthropologic) difference between European and American people and the Indian people, and also the fact that the overwhelming majority of the Indian population wears open type of footwear (sandals, chappals, slippers etc.) or nothing must have its impact as well. Although substantial differences have been identified between geographic regions of the country it is quite apparent that Indian feet are flatter, i.e. their foreparts - especially around the ball and waist part - are wider and lower than in case of European feet. Indian feet have shorter forepart: the distance of ball points from the heel part is relatively larger than that of European feet. The consequences are that footwear made on European shoe lasts do not really fit on Indian feet (i.e. they are not comfortable) and wear off quickly. Further distinction should be between different regions of the country. All this means that specially designed shoe lasts should be used for footwear produced for domestic sale in India.
Due to the biological acceleration - which is especially fast in developing countries - anthropometric surveys should periodically be repeated. Since India has large population and a very complex ethnic structure, foot measurement should be extended to various geographic areas to investigate their special features and the deviation from other regions. Technology development also requires more and more refined data for shoe last design and manufacture, for engineering patterns of footwear components and for supply of well-fitting shoes for the local population. Availability of comfortable footwear will reduce orthopaedic complaints, prevent development of static foot deceases which will certainly be reflected on the medical expenses of the Government and individuals. Technical assistance provided to the Indian rural areas offers a good opportunity to connect them with mini-surveys which will provide useful data for designing and supplying appropriate shoe lasts. By collecting these data a unique information base can gradually be built which provides reliable inputs for comparison of various regions of the country, as well as to supply guidelines for manufacturers and especially retailers regarding optimum size ranges and distribution of sizes when marketing footwear.