DEVELOPMENT OF EQUIPMENT FOR THE LEATHER AND DERIVED PRODUCTS INDUSTRIES

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Abstract

Primitive tools made of stones and bones were the first equipment used for removing unwanted substances (fat, meat, hair) from the cured/conservated (by minerals) animal hides in order to protect the human foot and the body. For thousands of years only pits, various hand tools and simple machines were used in processing leather and making derived products such as shoes, gloves, bags, belts, harness and upholstery. With the gilds manufacturing processes were split into distinct operations that facilitated the construction of mechanisms and machines to assist manual workers or later to replace them. Mechanization of leather processing and leather products production started with the industrial revolution and accelerated by the invention of electric engines. Tanneries making leather from raw animal hides/skins use today heavy moving vessels (paddles, drums, mixers), mechanical and hydraulic equipment became a capital intensive and energy consuming industry. Nevertheless, basic principles of leather processing has not changed, automation made a limited impact on this industry. Chrome tanning will probably dominate leather making in the next decades, more and more through feed types of machines will be applied, but solid and liquid waste recycling or disposal remains the major problem of this trade. In spite of introduction of new and productive technologies (CAD/CAM, injection moulding etc.) leather products manufacturing is still a labour intensive industry. Future development is expected from robotization, further computerization, use of biotechnology and artificial intelligence. Use of commodities made of leather (derived from animal hides/skins) will be influenced by tendencies in meat consumption (raw hides/skins are by-products of the meat industry), achievements of the material science (development of synthetic leather substitutes having the same or even better hygienic and wear properties as leather) and additive manufacturing (e.g. 3D printing.)

Keywords: tannery, leather processing, shoe, footwear, leather goods, gloves, leather products, machines, equipment.

Introduction

The term "leather industry" used in the everyday life and economy covered and still covers a fairly wide range of manufacturing activities starting from production of tanning chemicals, through leather and fur processing to making commodities such as footwear, gloves, leather goods (bags, small/flat goods, belts etc.), garment and headgears, furniture and car/airplane upholstery, balls and harness. Finished leather is also used for book binding and office accessories (e.g. folders), packaging, decorations etc. Moreover, there is a specific direction in industrial art using finished leather.

Like in all productive areas of the human life processing raw hides into leather and making products from us footwear, garment (including gloves) and other leather goods (including harness) was done manually by using simple tools such as knives, needles etc. Initially goods made of leather were used by the makers and their close relatives/families. The early craftsmen started to make products for others (e.g. for exchanging them with other goods), the productivity became an issue. Refined [manual] skills, discovering useful effects of other [auxiliary] materials (e.g. tannins in plants), improving [hand] tools properties (e.g. metallic knives) were instrumental in improving functionality – and later the look – (i.e. the quality) of these goods and reducing the time spent for making these goods. Diversification of human life, appearance of new functions by civilization and urbanization, desire for aesthetics (fashion), cultural changes widened the range of requirements against goods made of leather and increased the quantitative demand for them. The industrial revolution emerged in the second half of the 18th century brought the engine and mechanics that could replace human [muscle] efforts and certain elements of [manual] skills in all professions. Leather processing and leather products manufacturing followed and follows today the general trends in modernization of the technology from mechanization (introduction of machines) through application of [new] chemicals, biological processes (e.g. for unhairing raw hides/skins), automation, using computers (CNC) to robotization. Innovation in this trade is based mainly on adaptations of solutions discovered or developed in other (predominantly machine building) industries.

Leather processing (i.e. conversion of animal raw hides and skins into leather) and leather products manufacturing – though they are referred by public, economy, statistics etc. as one trade – differ substantially. (NB. The increasing use of leather upholstery in automobiles and the growing share of leather substitutes in leather products gradually eliminate the interdependency of leather and the products trades.) Tanneries where leather is made are capital intensive, while making of leather products (such as footwear, gloves, [hand]bags, fur coats and leather garment) is still – in spite of using fairly sophisticated equipment – a labour intensive activity. The possibility of processing large quantities (up to several tons) of hides/skins and leather in batches and the size of individual pieces (10-40 kg/skin or 1-4 m^2/leather) led to using heavy machines in tanneries. In contrast, leather products are smaller (0.1-2.0 kg/pair of shoes and gloves, 0.1 kg of purses/wallets or 0.3 kg of handbags or 5.0 kg of luggage), footwear and gloves need to be made in different sizes, so machines for making these items are smaller (in power consumption and volumes) and have more refined constructions. There is a wide variety and amount of chemicals and water used in leather processing; at the same time leather products manufacturing is nearer to mechanical engineering.

This paper deals with the development (history, present and future) trends of key and most important equipping used in the leather and derived products value chain.

Types of equipment

The large variety of operations for which equipment are used makes it difficult to classify machines used in leather and leather products industries. Nevertheless, based on their *functions* the following grouping may be made.

1. Leather processing
   - *a)* vessels: paddles, drums and mixers;
   - *b)* rotation machines:
     - bladed: fleshing/scudding/unhairing, shaving, sammying;
     - non-bladed: dewatering, setting, staking, buffing;
   - *c)* band-knife splitting;
   - *d)* dryers: convective, vacuum;
   - *e)* softening/staking: armed, vibration;
   - *f)* presses: ironing, embossing, rolling;
   - *g)* painting: spraying, coating;
   - *h)* surface measuring: mechanical, electronic;
   - *i)* handling and transporting: forklifts, conveyors, manipulators;
   - *j)* automation: mixing, weighing, dosing, process control, robots;
   - *k)* environmental protection: effluent treatment (e.g. pumps, mixers, aerators; dewatering).
2. Leather products manufacturing:
   - *a)* design/pattern engineering: CAM software, rapid prototyping;
   - *b)* material/component division: press/die cutting, vibration knife, fixed- and band-knife splitting, skiving, perforating;
   - *c)* sewing: shoe upper, welt, sole; gloves and fur; luggage; embroidering;
   - *d)* surface treatment: scouring, ruffing, polishing, embossing;
   - *e)* edge treatment: folding, binding, burning, burnishing, trimming, scouring;
   - *f)* riveting and eyeleting;

g) forming/shaping: pre-forming/moulding; pulling over, lasting (toe, heel-seat, side);
h) conditioning: shoe uppers, driers, heat-setting;
i) nailing and screwing;
j) presses: interlining, sole, heels;
k) direct shoe soling: vulcanizing, [injection] moulding;
l) finishing: cleaning, ironing, brand marking, spraying/painting;
m) packaging;
n) in-plant transport: conveyers.

Remark: Quite some machines (e.g. cutting, splitting, skiving, edge binding, sewing) – exactly the same or very similar – are used in footwear, leather goods (bags, small/flat and travel good, belt), glove, upholstery and leather garment making. However, only band-knife splitting machines, [embossing] presses, sprayers and some in-plant transporters work on similar principles, but even they are different (especially by their sizes) in tanneries and leather products manufacturing.

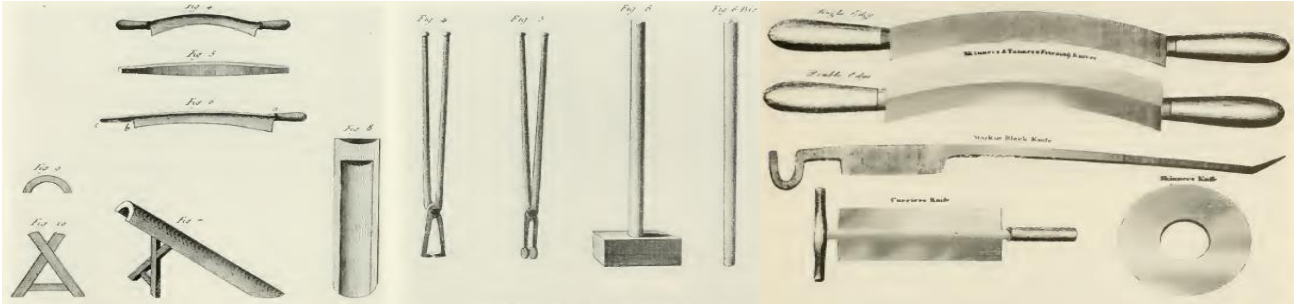
As in case of all other equipment, leather processing and leather products manufacturing machines may be mechanical, hydraulic, pneumatic (and their combination); human operated and [semi]automatic (including electronic and numerically controlled/CNC).

The history of mechanization

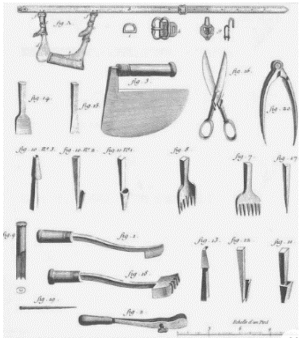
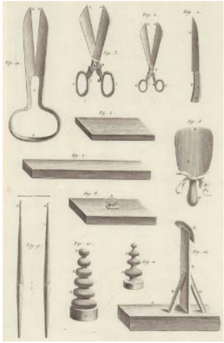
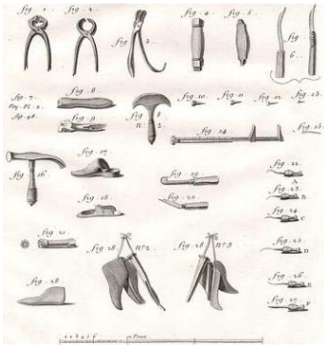
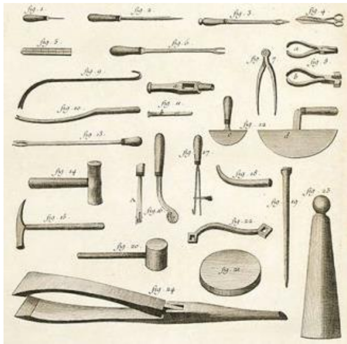
It would not be an exaggeration to call leather the first human industry, since the wearing of animal skins goes back to the beginning of human existence. Before early humans mastered the art of weaving, skins from animals slain for food (with and without the fur) were utilized for garments, footwear, headgear and protective clothing. (Tanning of Leather, n.d.) Bone tools found in Contrebandiers Cave on the Atlantic coast of Morocco from between 120,000-90,000 years ago for different activities, including likely leather and fur working, and were found in association with carnivore remains that were possibly skinned for fur (Hallet at al., 2021). Primitive men made preserved leather by using animal fat and converted it into clothing (to cover the body and feet), shelter, containers etc., i.e. in the very early history of mankind what we know today leather processing and leather products making were not separated activities.

Tanners, cobblers/shoemakers, glovers, furriers (craftsmen) of old times were fully skilled and dealt with their products from the very first stages till the delivery to the end users. When artisans organized the early guilds, it appeared that some of them were more cleverer/skilled/experienced/faster in performing certain operations (e.g. fleshing, sewing, finishing). The production processes started to broke into *operations* that were performed by the specialized workers in order to improve productivity and quality of final products. This facilitated the improvement of existing and even development of new tools (e.g. those made of iron/steel) and simple mechanisms (e.g. pulleys) assisting in performing [part of] distinct operations.

Hand tools such as knives, pincers, hammers etc. may be regarded as the very first steps in mechanization of certain processes or operations as they extended the manual power and made more effective the human work (*Figure 1*). In fact these hand tools are specific appearances or combinations of [some of] the simple machines (inclined plane, lever, wedge, wheel and axle, pulley, screw).



a)

b) *c)* *d)* *e)*

Figure 1. Hand tools in leather processing and leather products making in the 18th-19th centuries
a) tanner (Welsch, 1964); *b)* beltmaker; *c)* harness maker (Diderot et al., 2013); *d)* glover (Diderot et al., 2013); *e)* cobbler (Diderot et al., 2013)

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The *machine* is a device, having a unique purpose, that augments or replaces human or animal effort for the accomplishment of physical tasks (The New Encyclopædia Britannica, 1984). The purposes of first machines were to assist craftsmen in performing simple movements or operations not requiring specific skills or experiences – by no means complete processes. The appearance and success (i.e. proven usefulness) of the first used machines accelerated the splitting of the making (of leather and its derived products) process into smaller/simpler operations for which machines/mechanisms could imitate/replace the movements of the human body – specifically human hands. In other words the early (ancient) machines made simple movements, but they could multiply human efforts/forces, repeat movements precisely and/or speedily and they did not get tired. At the same time they were controlled by humans and the driving power/force was also supplied by humans or animals (an example is shown on *Figure 2*). Attempts were made for using water for driving machines e.g. for milling tanning barks or moving drums, but due to dependance on certain geographic conditions this approach had no impact on the leather-based industry.

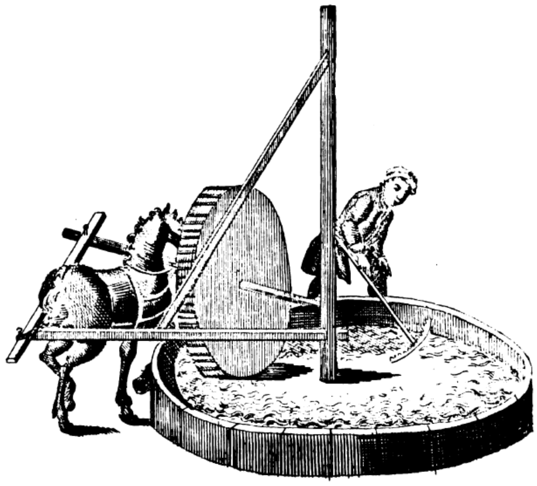
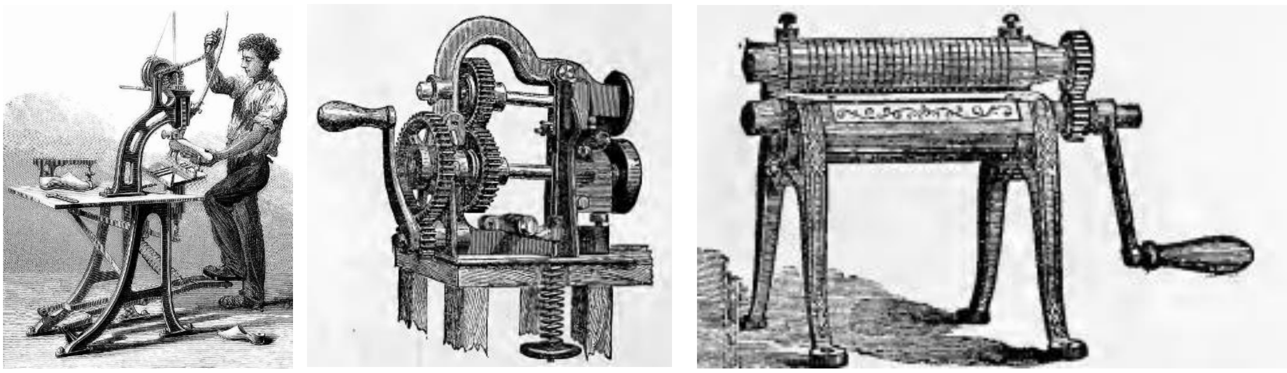


Figure 2. Bark chopping in the 18th century
A new and complete dictionary of arts and science, 1764

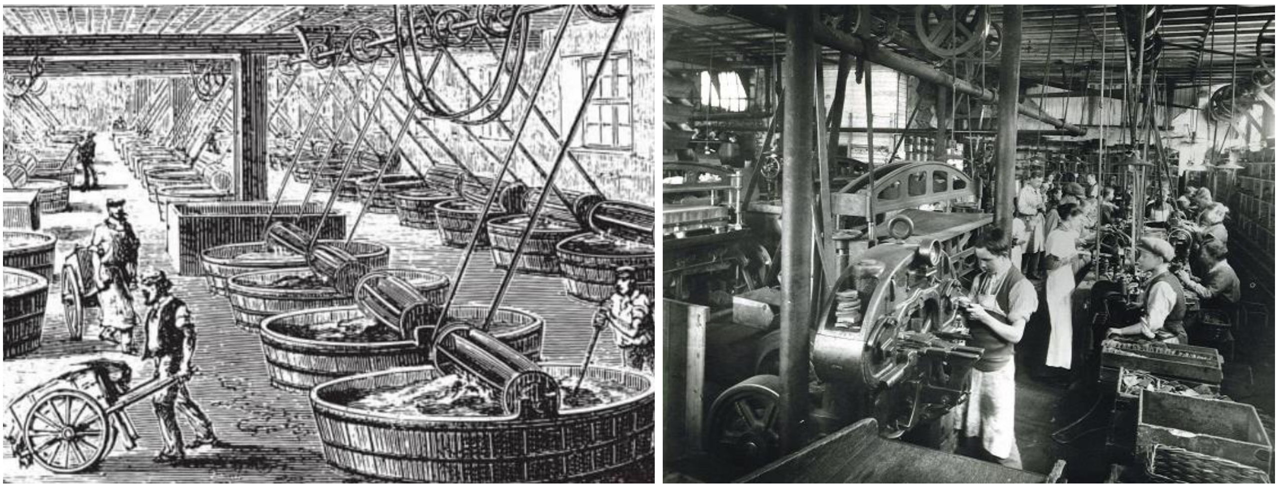
There are no proven evidences for what was the operation in which mechanisms more complicated than [hand] tools were used first. For long time primitive or later even fairly sophisticated mechanisms were moved by humans – by hands and/or feet (through treadles/foot pedals). Such machines were used in shoemaking (*Figure 3*), but not in leather processing until steam and later electric engines appeared.



a) *b)* *c)*

Figure 3. Manually operated machines in leather products manufacturing
a) sole nailing (History of the shoe trade, n.d.); *b)* edge levelling machine;
c) strip cutting machine (both Sewing Machine Gazette, 1881)

The industrial revolution brought steam engines by end of the 18th century that could be used for powering machines. However, a steam engine could provide far more power than a single machine would require, so the *line shaft system* was used for distributing kinetic energy among individual machines (*Figure 4*). The mechanical power came from a single massive steam engine, which turned a central steel drive shaft that ran along the length of the manufacturing plant. Subsidiary shafts, connected via belts and gears, drove individual machines.

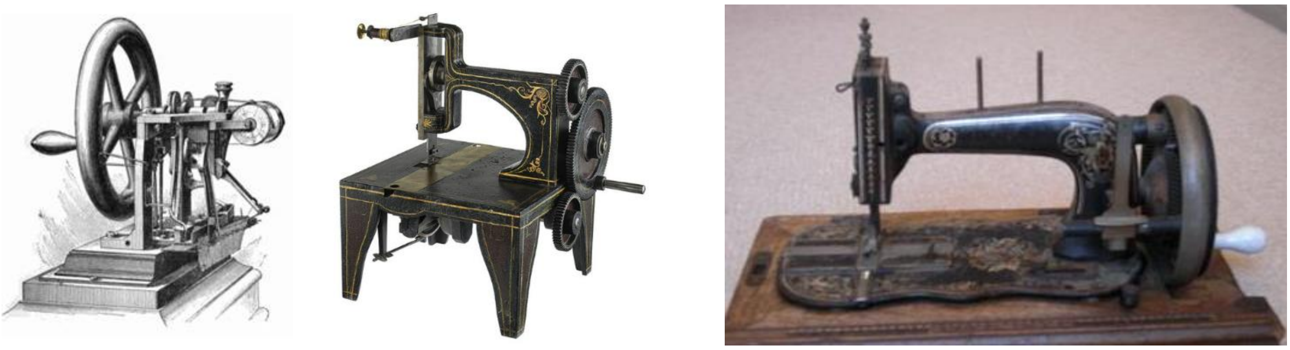


a) *b)*

Figure 4. Line shaft systems used
a) in a tannery (Pad & Quill, n.d.) and *b)* in a shoe factory (Northampton Museums, n.d.)

Another factor that helped mechanization of production processes was the invention of the Bessamer *steel* in 1855 that could be produced in masses and had good physical properties. The introduction of *electric motors* and fast development of electric power supply networks around the turn to the 20^{th} century made it possible to drive individual machines independently from others, whereas their efficiency surpassed substantially those of steam engines, caused less work accidents than those driven by line shafts. Furthermore, electric power could also be used for generating heat (e.g. for drying, embossing, ironing) and for local lighting of working zones. All these provided freedom in arranging machines in production plants according to the technology flow and made possible to introduce conveyers used later widely is shoe assembling plants.

The invention of the lockstitch sewing machine (by E. Howe in 1845, mass produced by M. Singer from 1860 – *Figure 5*) gave a highly effective tool to all textile and leather products manufacturer (Oelz, 2017). The idea inspired others and soon specific sewing machines were constructed for shoe welt and sole stitching. By early 1900s the first electric motor driven sewing machines appeared in the market, so the productivity of shoe upper and other leather goods assembling increased substantially, whereas the quality of seams improved as well.



a) *b)* *c)*

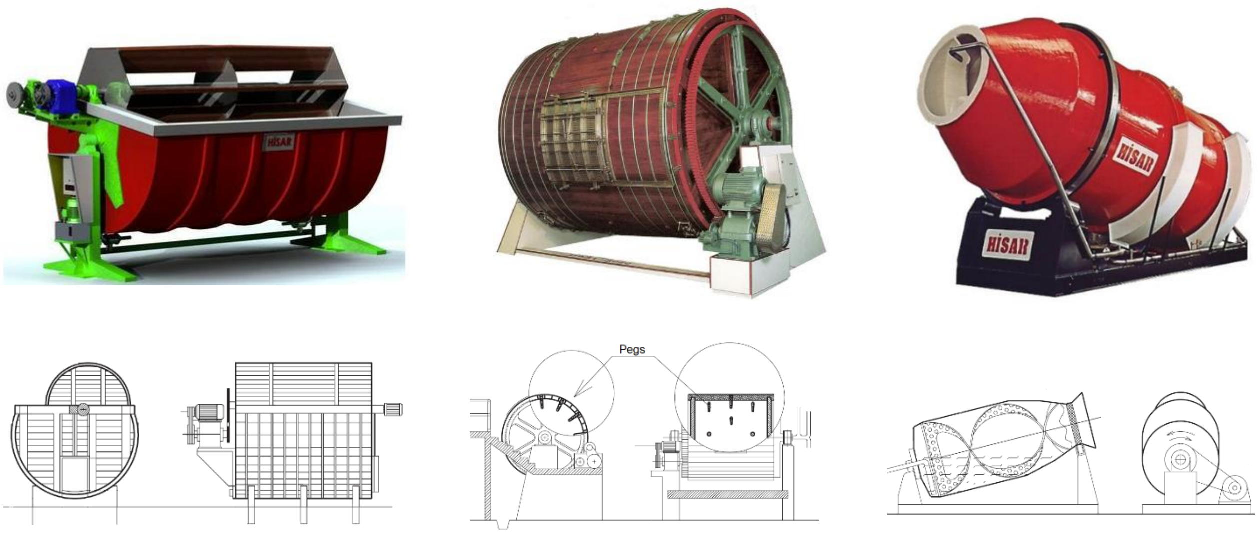
Figure 5. The invention of the sewing machine
a) Howe's sewing machine (Steemit, n.d.); *b)* Singer's sewing machine (Palmer, 2015);
c) Singer sewing machine mass produced in 1965 (BBC, n.d.)

The next major step in development of equipment used (not only) in leather related industries was the introduction of *electronics and automation*. Mechanical devices has been gradually replaced by electronic sensors and displays (e.g. photocells in leather area measuring in bridge type die cutting presses, measuring and displaying temperature, timers). Nevertheless, practically all machines used in tanneries and leather products manufacturing were just simple extensions of or assistance to the human operator until mid of the 20th century: each machine required the intervention of (one or more) workers. Some equipment even required to develop special skills for their operators (e.g. leather shaving, stitching, shoe lasting). To eliminate human interventions from performing an operation or their sequences (sometimes complete processes) *automatic* machines were developed that after once being set work automatically except for applying the power, lubricating, supplying material and shutting off the power. (E.g. throughput tannery equipment, vibration leather staking, combined shoe insole making, high-frequency welding machines may be regarded as automatic machines.) Very recently *robots* started to appear in leather and its derived products manufacturing (e.g. unloading tannery machines, roughing and applying adhesives). These are autonomous machines capable of sensing their environment, carrying out computations to make decisions and performing actions in the real world (Robots, n.d.).

In spite of all efforts and attractive achievements in modernizing leather processing and making products from it basic technology principles are practically unchanged. The early processes used to make leather, and craft with it, remain very similar to some of those still used today. Shoe uppers, [hand]bags, gloves are assembled (mostly stitched) the same way it was done centuries ago, though the sewing and some special (e.g. skiving, edge binding, eyeleting/riveting) machines increased the speed of the related operations.

Tannery equipment

Ancient, as well as modern leather processing are a combination of chemical and physical interventions with raw hides and skins in order to convert them into leather. Before the industrial revolution tanners and tanneries concentrated on treating the material with various stuff (mostly of natural origin) dissolved in water. Physical operations included only scudding (fleshing and dehairing) and softening.



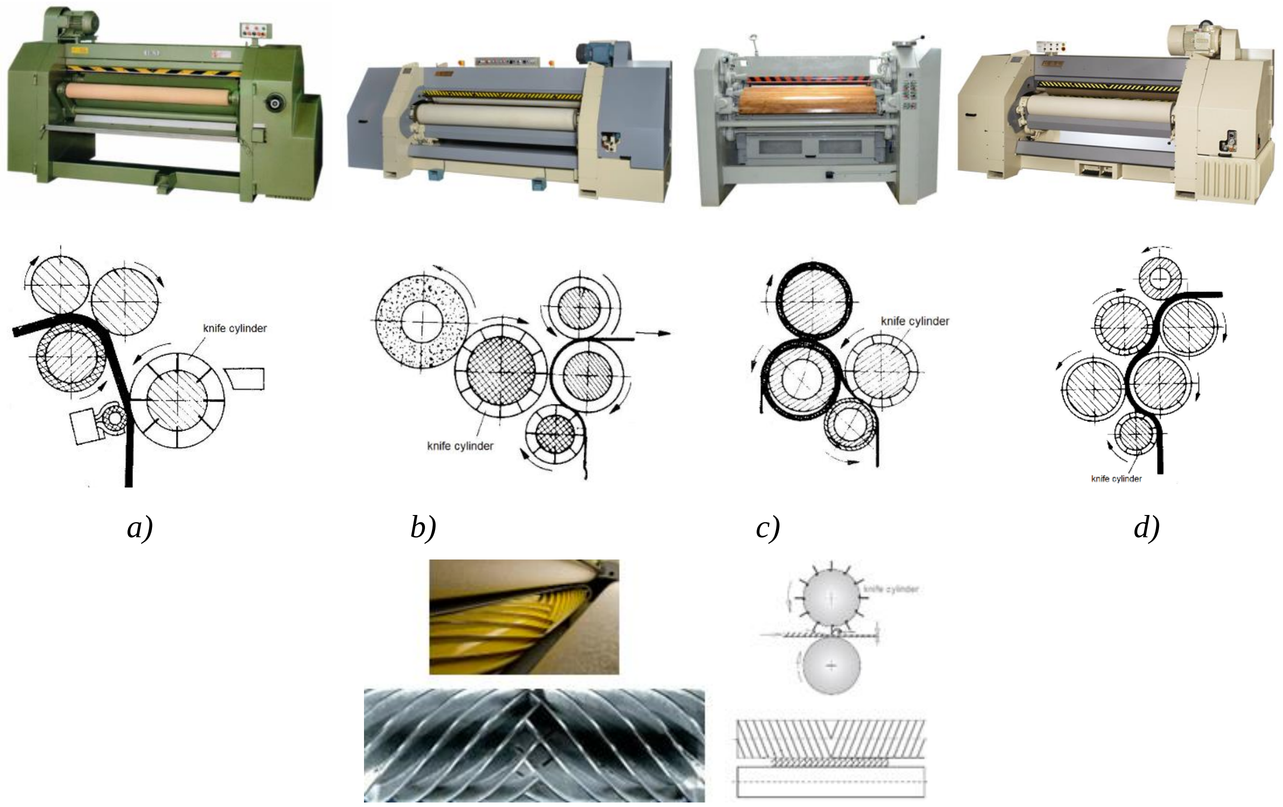
a) *b)* *c)*

Figure 6. Tannery vessels
a) paddle (ePlaza, nd.); *b)* drum (Hisar Tannery Machines, n.d.1);
c) mixer (Hisar Tannery Machines, n.d.2); *Schemes* in Repetto et al., n.d.

As in the early eras, key equipment of tanneries are *vessels* in which chemicals reacted with leather of its actual status (raw hides/skins, pelts, crust, semi-finished). The time required for achieving the desired effect of such reactions is fairly long (in case of pits in ancient tanneries it lasted even several months). The positive effect of stirring the liquid and moving materials in the bath was discovered thousands years ago. First paddles were used for generating these movements, then closed rotating drums ("spinning pits") were introduces in tan-yards. Tannery machinery manufacturers took over ideas from other industries: e.g. the Y-type drum was inspired by household washing machines, mixing drums work on the principle of concrete mixers used in in construction building. Examples of modern versions of tannery vessels are shown on *Figure 6*.

Nowadays these vessels are made of stainless steel or plastics (fiberglass, polypropylene), whereas the majority of drums are made of wood (mainly oak, larch). Automation (e.g. dosing of chemicals, water supply, rotation control) make the work with these equipment easier. However, loading and unloading of tannery vessels is still an unresolved problem. Though fork lifts assist humans in accomplishing these tasks, there are quite some losses of chemicals and water. Controlling and servicing tannery vessels impossible without essential infrastructure such supplying water and chemicals, collection of effluent (including recycling).

Remark: There is another equipment named drum used for desalting raw hides. However, this is a cylinder having a sieve liner letting out the salt shaken from hides. Like the milling drum it is not associated with liquid floats.



e)

Figure 7. Tannery machines using knife cylinders

a) fleshing (OfficineRM, n.d.); *b)* sammying (GBL, n.d.1.); *c)* shaving (Zimeks, n.d.); *d)* setting out (GBL, n.d.2.); *e)* knife cylinders; *Schemes* in Kovács, 1984

Most of the mechanical and hydraulic machines working with wet materials (i.e. in wet processing such as soaking, liming, bating and tanning) use *blade/knife cylinders* (*Figure 7*). They look fairly similar and even their mechanical scheme does not differ substantially (Kovács, 1984). The major technical parameter of these are fairly large, heavy and energy consuming equipment is their width determined by the size of hides/skins/crust (bovine, goat/sheep, full/side etc.). The respective operations involves minimum one worker (splitting, sammying, setting out and shaving of heavy hides need two operators) for feeding the machines and controlling the state of the material. The only notable development in this area was the combination of summying and setting out in one through feed machine, whereby the operator just loads the material on one side and removes the processed material on the other side of the machine.

Animal hides/skins in before and after tanning (irrespective of the tanning agent), as well as in dry stage (after drying) have uneven thickness according to their topographic areas, whereas leather products manufacturing requires constant material thickness. *Band knife splitting* machines in which the knife moves with high speed perpendicular to the advancement of the material produce grain side of uniform thickness with tolerance ±0.2 mm in wet or ±0.05 mm in dry splitting. If the splitting is made after liming or bating (i.e. in wet stage) then the flesh side layer may also be processed finished (although its quality will be lower than that of the grain side) e.g. into suede, patented/coated leather useful for shoe uppers or linings. Splitting improves the yield of the leather production. The construction of bend knife splitting machines used in wet and dry stages are practically the same; some suppliers offer machines that may be split leather both in wet and dry stages. The operational principle of this machine has not changed during the past two centuries, though the precision improved and some electronic controls have been added (*Figure 8*). In reality bend knife splitting machines may be regarded as the first occurrence of the continuous operation (also named as through feed/put) equipment in leather processing.

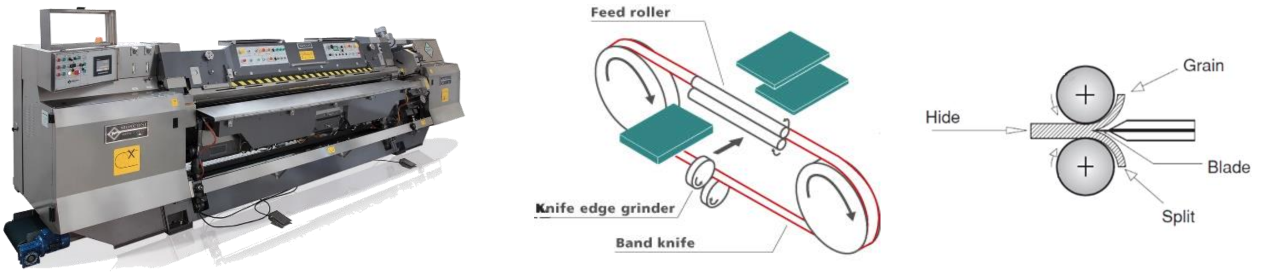
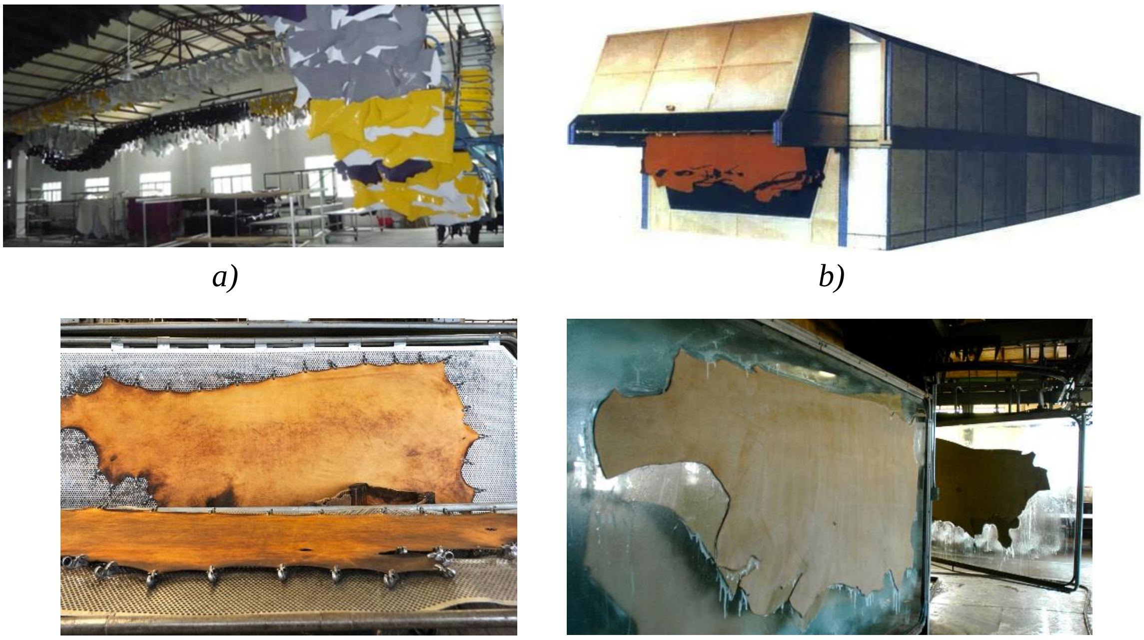


Figure 8. Tannery splitting machine (Mosconi, n.d.)

Setting out removes water and dissolved chemicals used for leather tanning by pressing, but the humidity of leather remains approximately 40%. For further reduction of leather water content *drying equipment* are used (*Figure 9*). The straightforward solution is to hang up leather and get it dried by convection. Achieving the targeted low humidity (usually around 15%) is subject to the atmospheric parameters (temperature, relative humidity and velocity) of the drying air surrounding the material and would take fairly long time if not controlled this process. Suspension drying may be performed by a continuously overhead moving chain conveyor installed under the ceiling of the tannery's finishing plant or in drying chambers/tunnels in which the temperature of the ventilated leather is regulated. The efficiency of drying coupled with increased area yield is achieved by toggle drying, whereas the leather is stretched over a perforated plate by fixing its edges with clips. (Frames are often made in two parts to enable mechanical extension.) Another, but now rarely used method is when leather after samm/setting is stuck to glass or vitreous enamelled plates using a starch based paste and then these plates are placed in drying chambers or moved through a drying tunnel.

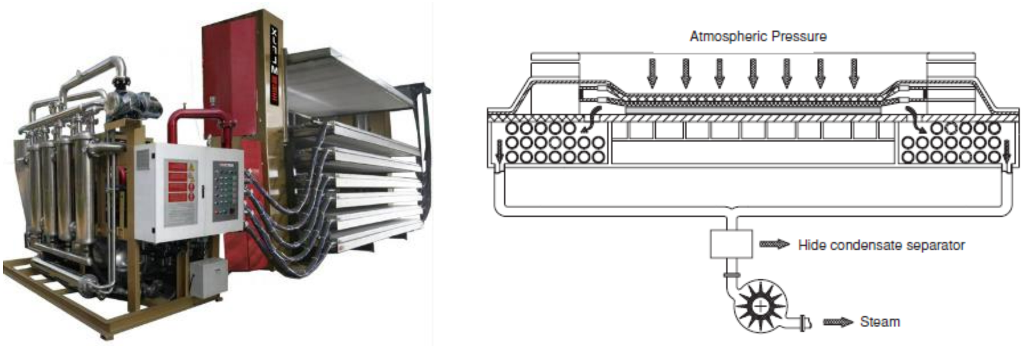


a) b)

c) d)

Figure 9. Convective leather drying
a) suspension (Alibaba, n.d.1); *b)* tunnel (Alibaba, n.d.1);
c) toggle (Horwin, n.d.); *d)* glass (Horwin, n.d.)

A relatively recent (although nearly 50 years old) development in leather processing is the use of vacuum drying (*Figure 10*). The leather is placed grain down on a heated and polished stainless steel plate, then a hood is lowered on a timed cycle to form a seal with the heated plate and the air pressure is reduced from the enclosed volume via the hood by vacuum pump. This lowers the boiling point of water causing fast evaporation (Daniels, 2021).



a) b)

Figure 10. Vacuum drier
a) Alibaba, n.d.2; *b)* Daniels, 2021

One of the oldest mechanized operation in post-tanning is *staking* that increases the softness of leathers (at the same time it increases their area as well). Earlier arm type staking machines were used, today mostly high output vibration machines are used for this purpose (*Figure 11*). The operation of dry milling, when dried leathers are placed in rotating drums also aims at softening the material (Daniels, 2021).

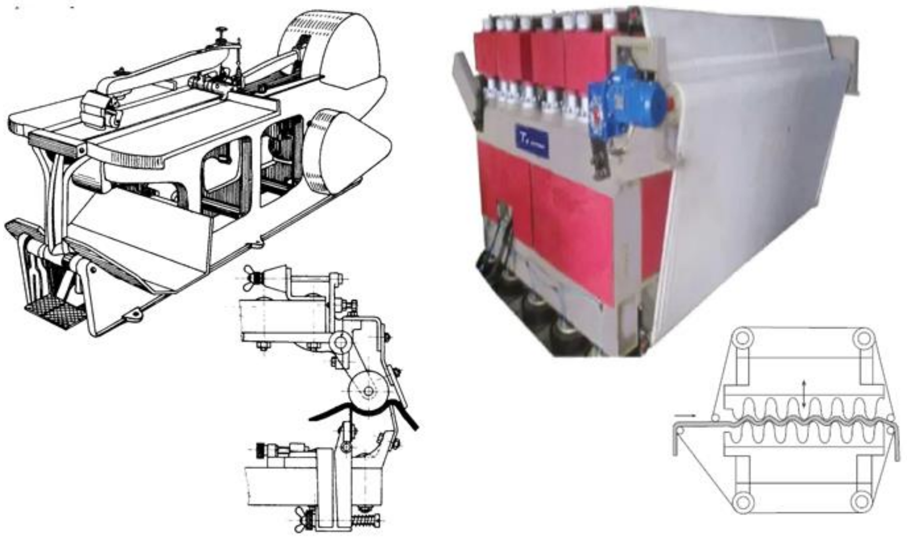


Figure 11. Arm type (left) and vibration (right) staking machines (Indiamart, n.d.1; Kovács, 1984; Daniels 2021)

Dyeing leather is the process of applying a colored pigment mixed with a base (usually alcohol, oil, or water) to leather fibers of leather such that the visible color of the leather changes. Dyestuffs are used in liquid form and usually they react with leather in dyeing drums.

The top (grain) surface of the leather may be covered with a thin layer of dyestuff for either enhancing the aesthetic appearance of the grain with pigment or for covering low quality (faulty) grains or adding an artificial grain (e.g. to split leather). Thin grain finish is applied by rotating *spraying* machines usually connected to drying chambers (*Figure 12*).

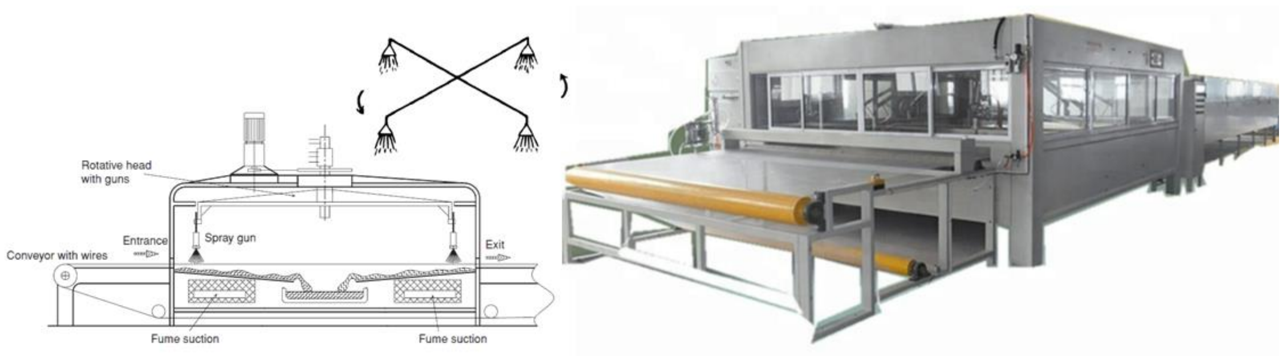


Figure 12. Rotation leather spraying plant (Repetto et al., n.d.)

Another way of surface pigmenting is transferring the wet finish from a stainless steel engraved roller onto the leather surface. Respective machines are named as *roller coaters* (*Figure 13*).

Figure 13. Roller coating machine (Alibaba, n.d.3)

Leather coating is the only area where computer aided manufacturing (CAM) technology is used in leather processing. Dyestuff itself produced in the chemical industry by using computer colorimetry. In leather finishing dyes are applied to the sample leather, then the effect is measured and the recipe is adjusted by computer programs to achieve the targeted effect.

There are other *leather finishing machines* that are used if and when special look or characteristics should be provided to the final product (*Figure 14*). These are mechanical or hydraulic machines based on principles and performing respective operations that actually the same as 150-200 years ago.

Figure 14. Leather finishing machines
Buffing (Alibaba, n.d.4); Glazing (GBL, n.d.3); Roller (GBL, n.d.4);
Ironing (Bergi, n.d.); Embossing (Alpa n.d.)

The last operation of (light) leather manufacturing is to *measure the area* of the area of the final product(s). This was one of the first area where the traditional [pinwheel] mechanical machine was replaced by a [photoelectric] automat (*Figure 15*), which is capable of printing reports/summaries and supply data online to the company management system.

Figure 15. Modern leather area ensuring machine (Selin n.d.)

One of the development direction in constructing tannery equipment is replacing traditional machines operated by workers with through feed type versions. Beside the valuable fact that operating such machines need less skills (and training) from their operators, they also make possible to integrate them into production lines requiring less human labour. Attempts are underway in using robots for loading and unloading through feed types of tannery equipment. Another area where process automation has started to penetrate into tanneries is the control of operations performed in vessels (see above).

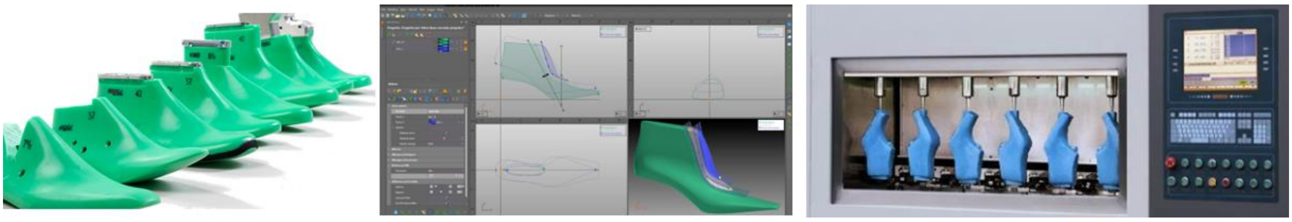
Transporting equipment used in tanneries include containers and general purpose fork-lifts.

The major problem of today's leather processing is *sustainability*. Tanneries use by-products (in fact wastes such as hides and skins) of the meat industry which depends on availability of animals suitable for eating their meat and the digesting/consuming habits/culture of the World human population that create demand. (In other words the leather industry turns the nearly 1.3 billion t/year – otherwise useless but harmful – residuals of the meat production into a valuable commodity used for manufacturing of clothing accessories.) Nevertheless, leather processing uses of chemicals: the most critical is the nontoxic three-valent chromium (Cr^{+3}) that may turn – but only in rare extreme conditions – into harmful six-valent chromium (Cr^{+6}). Moreover, processing raw hides and skins is associated with unpleasant odor, disposal or recycling solid wastes (especially flashings, chrome tanned trimming and shavings) and effluents discharged by tanneries requires serious efforts. Tanneries operating anywhere on the Globe use individual or common effluent treatment plant requiring specific infrastructure and equipment.

Footwear manufacturing

The complete shoemaking trade encompasses shoe lasts design and production, design and pattern development, leather and substitute materials manipulation (cutting), components (e.g. insoles, stiffeners, outsoles, orthotics) [pre]manufacturing, upper and bottom assembling, finishing, tooling (e.g. cutting dies, forming and injection moulds making). All these areas benefited from the technical development witnessed in the past two centuries: a wide range of specialized machines have been created, the CAD/CAM technology is integral part of modern footwear production.

Shoe last manufacturing has radically developed during the past fifty years (*Figure 16*). The first notable innovation was when wood was replaced by poly-ethylene that improved the precision physical stability of this important tool of shoemaking, whereas large stocks of expensive timbers (in seasoning) could be eliminated. The next step in automation was the introduction of computer aided design (CAD) in shoe last design and production preparation, as well as the invention and widespread use of multi-axis computerized numerical controlled (CNC) last turning machines. Nowadays the applicability of 3D printing for shoe last manufacturing is under consideration.

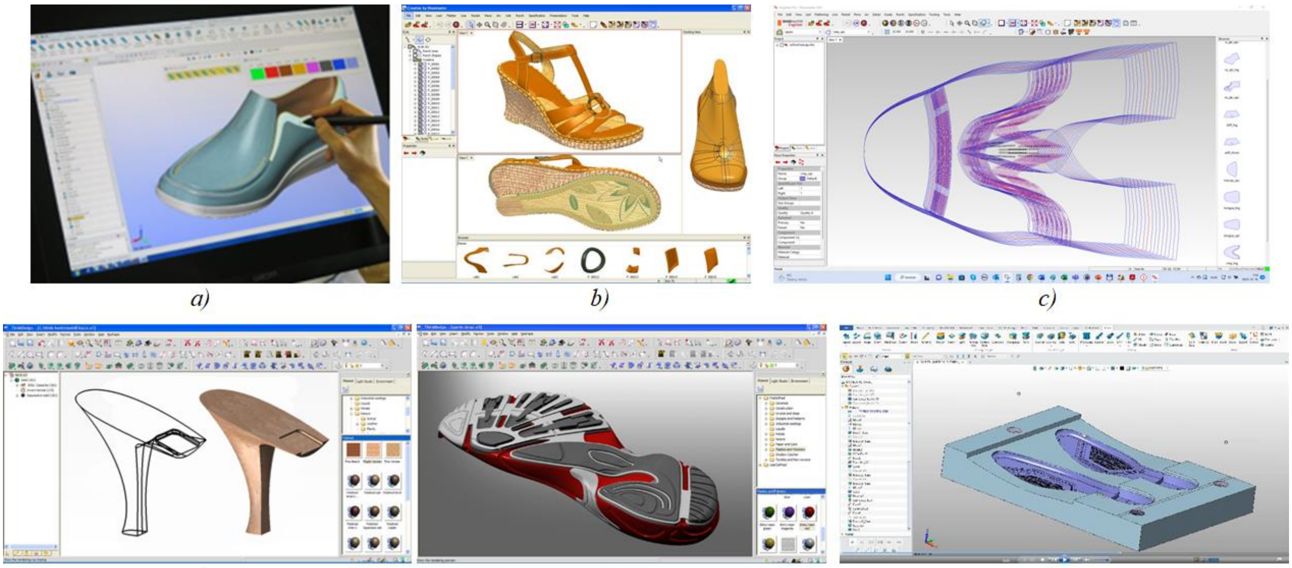


a) *b)* *c)*

Figure 16. Development stages in shoe last manufacturing
a) plastic shoe lasts (Fagus n.d.); *b)* computerized design (Newlast, n.d.);
c) multi-axis CNC turning (Made-in-China, n.d.1)

Product development

Shoe design and pattern engineering are the crucial activities in product development. Along with the garment industry footwear designers adopted the *CAD technology* right after the pioneering construction and machine engineering trades. Several software houses offer quite versatile applications for aesthetic design, pattern development, material costing and supplying digital information for other areas of shoe manufacturing such as rapid prototyping, tool/mould design, leather and its substitutes cutting, automatic stitching etc. (*Figure 17*). Designers can create new styles by using CAD software and produce photo-realistic pictures that can eliminate the need for making physical sample shoes. Shoe engineering by computers has not only replaced the mechanical pattern grading machines but also increased the precision of production preparation, provides better fitting components and shue uppers. Certain "standardization" has taken place with regards data formats (e.g. .stl/.wrl for 3D object like shoe lasts and moulds, .dxf for 2D objects such as flat components) that permits exchanging digital information among equipment (e.g. CAD software, cutting machines) of different origins (Schmél, n.d.1).



a) *b)* *c)* *d)* *e)* *f)*

Figure 17. Shoe CAD (curtesy of ATOM-Schoemaster)
a) sketching; *b)* design; *c)* pattern grading; *d)* heel design; *e)* unit sole design; *f)* mould design

Components [pre]manufacturing

Development of shoe machinery follows the trend in changing the material base used for footwear manufacturing. Leather is being replaced by substitutes that may have better physical and wear properties. Shoe components originally were made of leather, now many of them are made entirely (e.g. heels, stiffeners) or partially (soles, linings) of substitutes having homogeneous structure and requiring completely different technology (e.g. injection moulding). The overwhelming majority of footwear sold worldwide are from mass production, which is assembling components usually supplied by other specialized manufacturers.

Shoe *components productions* are today very productive thanks to the high level of mechanization and automation. The majority of prefabricated *insoles* (*Figure 18*) are made of leather- or alpha-cellulose board coupled with cardboard and steel shank (if required). By this there is no need any more for traditional machines developed for working with vegetable tanned leather insoles (e.g. fixed knife splitting, lip/rib opening and covering for Goodyear welted insoles). Combined insoles are made with a set of cutting, riveting, beveling machines and moulding presses. Injection moulding of plastic shanks into the cut insole split in its back-part has a limited use due to the costly tooling (moulds) requirements (Schmél, n.d.2).

Figure 18. Shoe (lasting) insoles (Beke, 1981)
a) Goodyear welted; *b)* combined; *c)* injection moulded

The crucial operation in making *leatherboard stiffeners* is moulding requiring sets of steel moulds. Unit *soles* may be prefabricated from sheet (leather, rubber or poly-urethane) by cutting and with several special machines (trimming, roughing, heel attaching, edge and surface finishing etc.). However, most of the unit soles are made by vulcanizing rubber or by [injection] moulding predominantly thermoplastic rubber (TR/TPR), poly-urethane (PU) or ethylene-vinyl-acetate (EVA) – earlier also poly-vinyl-chloride (PVC). Medium and high *heels* and their top-pieces are made of various – mostly thermoplastic – materials and made by injection moulding. Some heels are covered with the material of the shoe upper – usually this is done where the shoes are assembled.

Cutting

Cutting – especially leather – has always been and still is one of the most important operation in shoemaking, as the yield is directly related with [material] costs of the production. Therefore, leather cutters used to be the most skilled and experienced (and highly paid) workers. Manual cutting was replaced by die/press cutting when quantitative demand for footwear radically increased and mass shoe production emerged at the beginning of the 20th century. Cutting dies were originally made in shoe factories but today they are sourced from specialized suppliers using mechanical or hydraulic die bending equipment and other metalworking machines (e.g. electric welders). The first die cutting machines had mechanical constructions, which were soon changed for hydraulics offering higher cutting force, operate with much less noise and requiring less maintenance. For soft leather cutting swing-arm cutting presses were used. Leather substitutes such as synthetics/poromerics, coated fabrics, leatherboard/alpha-cellulose, rubber, poly-urethane etc. sheets may be cut in several layers: for them bridge type hydraulic presses are used (*Figure 19*).

a) b) c)

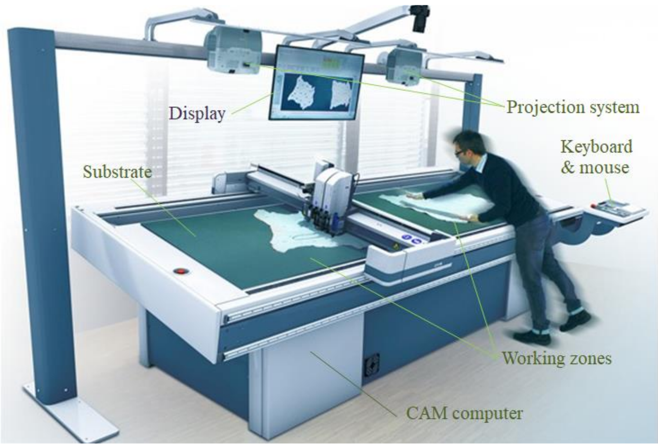
Figure 19. Hydraulic die cutting machines
a) swing arm (iigm, n.d.); *b)* travelling head (Indiamart, n.d.2); *c)* beam (Indiamart, n.d.3)

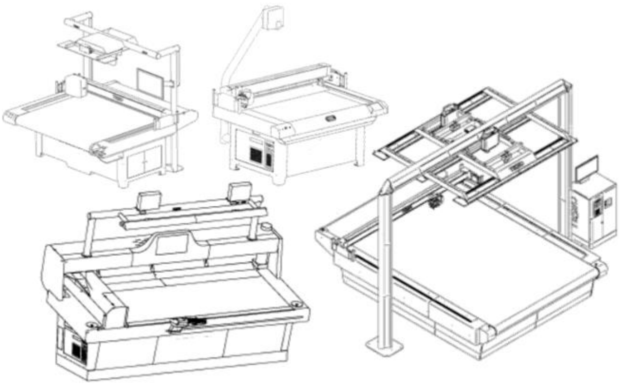
Travelling head cutting machines were successfully automated. Cutting dies are mounted on metallic plates and fixed on the head, whereas the digital(ized) shape of the die's contour and its orientation are electronically input together with the material size (width), the allowed cutting bridge (distance among cut pieces). The cutting program (either generated by the computer part of the machine or by an external system and then loaded into the machine) controls the movement of the travelling head, rotates the cutting die, advances the material when one row of components have been cut and changes the cutting dies.

Die cutting is very productive (especially in case of cutting multilayers leather substitutes). At the same time shoe size range to be produced require several sets of dies, frequent fashion changes makes shorter production orders that increases tooling costs, not to mention of the lead time associated with making/getting cutting dies for new styles. Die-less cutting options are the following:

- micro plasma: due to complex physical conditions its application for cutting shoe (and other leather products') materials is not feasible;
- laser: used for making perforated decorations of shoe upper components;
- waterjet: used by a few large-scale manufacturers producing shoe components made of hard leather substitutes;
- vibration knife: an oscillating blade is moved along the contour of the piece (shoe component) by a numerically controlled mechanism – this technology appeared to be suitable for cutting shoe upper and lining components – especially from soft leather.

Computer controlled vibration knife cutting machines appeared in the leather product industry be very end of the 20th century and dominate today the automated leather cutting scene. The head containing the oscillating knife, the stab/awl, the marking pen and two (or more) perforating punchers moves along the console (*y* direction), while the console moves along the cutting table (*x* direction) holding by vacuum the material/leather to be cut (*Figure 20*). Digital data of shoe components produced by a CAD system are load to the computer of the cutting machine, which may be retrieved on the display of the cutting machine and projected onto the leather. The operator can move and rotate the projected images of the components/pieces and place then at the desired position (with the multifunctional mouse), whereas the machine's program prevents overlapping and assist in bumping the contours. After the operator completes the layout of pieces on the material surface and starts the cutting operation first perforations, stabs and marks (if and where required) are made by respective tools of the machine head, finally the oscillating cuts the contour (and internal cuts if exist); thereafter the head moves to the next piece and so on (Schmél, n.d.2).





a) *b)*

Figure 20. Vibration knife leather cutting machine
a) machine architecture (Schmél, n,d,2); *b)* sample configurations

There are different configurations of these cutting machines (*Figure 20*). Machines having two projectors and wider cutting tables let operator to prepare the layout on one leather and while the machine does the cutting the worker can take the next leather and prepare the layout on it. Heads may have a router (instead of the oscillating knife) for cutting hard materials. There are machines that have two consoles with their own combined heads for increasing the speed/productivity of this operation. Nesting (preparation of the unique layout for leathers having their individual size, shapes and topography, as well as number, kinds and distribution of faults) may be made off-line on a separate machine: in this case the layout of pieces is forwarded to the cutting machine where it is just recalled when the respective leather is placed on the cutting table.

The automation of cutting leather (the most complex operation in shoemaking) brought about further results. The most modern cutting tables are equipped with overhead cameras for digitizing contours of leathers, topographic zones, positions and characteristics of faults marked by the operator by using a digital pointer. As quality requirements and orientation of shoe components are defined in the CAD system used for pattern engineering, the cutting machine's software can automatically generate the optimal layout (providing the best yield = minimum cutting wastes and ensuring quality of cut pieces) and control the cutting process accordingly. Robots can pick up cut shoe components and stack them according to their names and sizes on a nearby table/container (*Figure 21*).

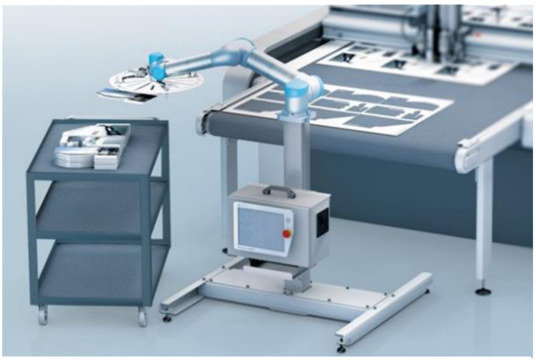


Figure 21. Robot collecting cut pieces
(Mind, n.d.)

Uppers of certain types of footwear (e.g. slippers, house and sport shoes), some shoe components (e.g. vamp linings) are [traditionally] made of textiles; actual fashion trends increase the demand for textile shoes. Although textiles (woven and non-woven fabrics, knitwear) may be cut by dies or vibration knives, when large quantities are in production then cutting devices are used in the apparel industry (*Figure 22*) are better choices.

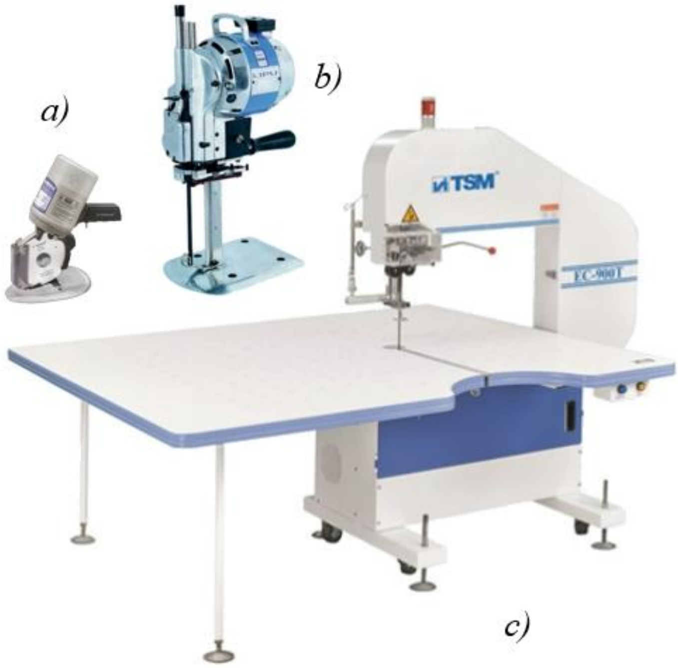


Figure 22: Textile cutting machines
a) round knife (Mithra, n.d.); *b)* straight knife (Mithra, n.d.); *c)* band knife (tsm, n.d.)

Shoe upper making (closing)

Perforated uppers (components) are used in summer shoes, sandals and also as decorations in closed shoes. Laser cutting machines (*Figure 23*) perforate upper leather components with high productivity, whereas shapes and positions of perforations are designed in (off-line) CAD systems.

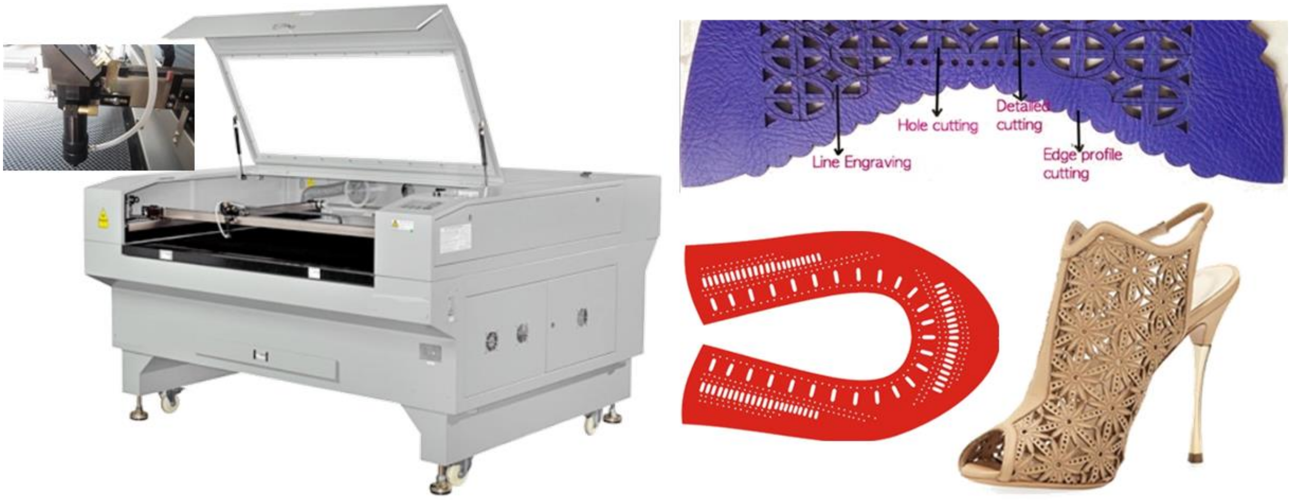


Figure 23. Laser cutting/perforating machine (Indiamart, n.d.3)

A great deal of shoe upper components are prepared right after cutting while they are flat. Especially in quality shoe production *splitting* of upper components is a must, for which band-knife splitting machines (working on the same principles and having very similar mechanisms as those used in tanneries – see *Figure 8* – but of smaller dimensions) are used (*Figure 24*).

Figure 24. Upper leather splitting machine (Camoga, n.d.)

Edge *skiving* machines are inevitable for ensuring smooth overlaps, fine clear cut edges and edge folding. The kinematic principle of splitting and skiving with moving band and bell knives is exactly the same (*Figure 25*): due to the substantial difference between the moving speeds of the knife and that of the material, the real cutting angle is far less than the actual angle of the knife edge (Schmél, n.d.2). This provides precise cutting/skiving of even very thin materials such as soft leather having 0.8-4.0 mm thickness.

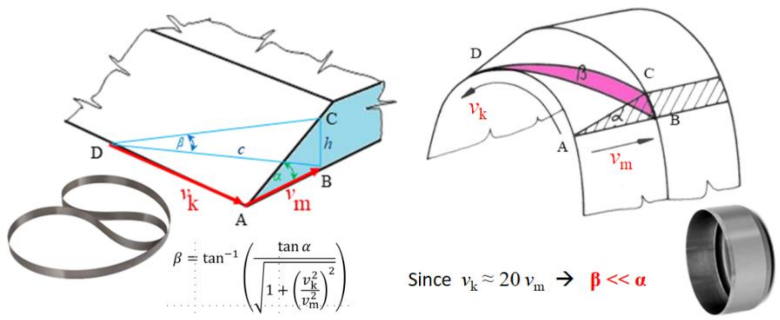


Figure 25. Comparison of the cutting angle with the angle of the splitting/skiving knife edge (Schmél, n.d.2)

Modern skiving machines have electronic control of skiving (width, angle, remaining thickness) and operational parameters (e.g. material feed and knife speed), memories for saving parameters, displays for entering data and showing the actual status of the operations (*Figure 26*). Electronic control provides easy changes of skiving profiles and parameters at every part of the shoe upper component contour.

Figure 26. Modern skiving machines
a) Dominex, n.d.; *b)* Sagitta, n.d.; *c)* Nippy, n.d.; *d)* Leathersplittingmachine, n.d.

Skiving may be performed by profile splitting as well, when the shoe upper or lining component is placed in a mould (usually made of silicone) cavity shaped as the negative 3D image of cross section of the component.

With negligible exemptions shoe uppers are assembled by *stitching* components together, whereas the seam may also serve as a decoration. The principles of forming lockstitches (they dominate in shoe upper making) and single/double chain stitches have not changed since the first [flatbed] sewing machines were invented in mid-1800s. The architecture and even the shape of modern sewing machines resembles those used 100-150 years ago. Notable and useful improvements made in the past nearly one hundred year include the introduction of post-bed and cylinder-bed constructions (*Figure 27*) making the assembling of shoe uppers much easier, as well as the following solutions:

- changing the foot/treadle drive with electric engines;
- quantitative improvements of certain features such as [maximal] speed (up to or even over 5,000 stitches/min) and larger hooks providing some more space for bobbins that may have lower thread of double length;
- central oiling;
- improved mechanical structures such as twin needles, combined and unison/compound feed, reversing, elimination of friction clutches and belt;
- electronic controls (e.g. stitch length, needle positioning – i.e. stopping when the needle is in its upmost or downmost position), [touch] screens etc.;
- attachments like thread trimmers, guides, [under and upper] lining trimmers, binding guides.

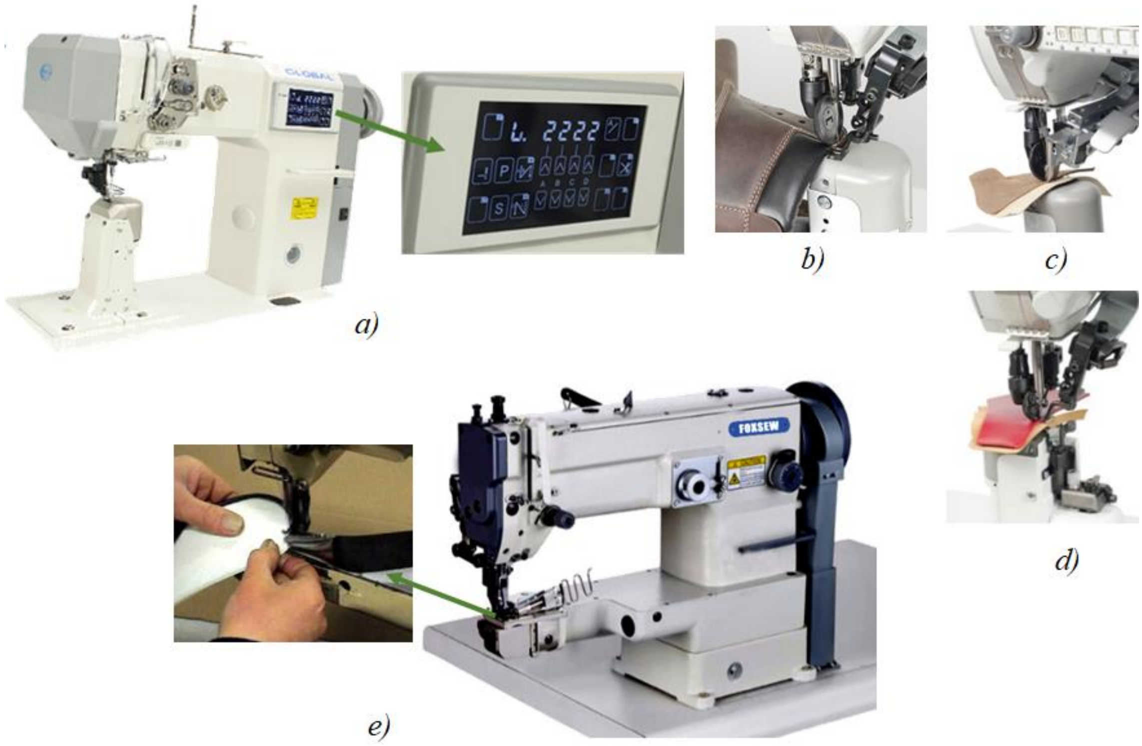


Figure 27. Shoe upper sewing machines and attachments
a) post-bed with electronic control; *b)* guide (Minerva, n.d.1); *c)* upper trimmer (Minerva, n.d.2); *d)* under trimmer (Minerva, n.d.3); *e)* cylinder bed with for edge binding (Foxsew, n.d.1)

These enhancements increased productivity and reliability stitching operations, reduced noise and the need for maintenance, help machine servicing, in general made the sewing machines more “user friendly”. Nevertheless, the quality and productivity of sewing operations is depends on the skill of sewing machinists. The inconvenience associated with frequent changes of lower thread bobbins (because of their limited size) that may need to be done in the middle of the seam, also rethreading for other thread sizes or colors are serious obstacles.

Automation of sewing shoe uppers resulted in some (or rather limited) achievements. In earlier bartack sewing machines the stitching process (trajectory) was driven by a grove disk which has been replaced by electronic control (*Figure 28a*) and the working area is now larger. These machines can attach bars (e.g. in sandals), make reinforcing (e.g. vee in Derby shoes) and or decorative seams (*Figure 28b*). There are programable sewing machines for assembling shoe upper components (*Figure 28c*) but only in flat and even for this pallets are needed for holding pieces together during the stitching process, which may be feasible when large quantities are to be produced of the same style/design.

Figure 28. Sewing automats

a) bartack (Goldstar, n.d.); *b)* decorative stitcher (Xadeko, n.d.); *c)* shoe upper assembling (Paco Bazán, n.d.)

A wide range of single- and multi-needle, flat/post/cylinder-bed, left- and right-armed, light/medium/heavy duty lockstitch sewing machines have been developed for various shoe upper making operations based on the traditional core mechanism. At the same time *special sewing machines* having different constructions and used in other industries (e.g. glove, fur confectioning, leather goods) were adopted or adapted for footwear manufacturing: *Figure 29* demonstrates typical types and their applications.

a) *b)* *c)*

Figure 29. Special shoe upper sewing machines

a) moccasin (Foxsew, n.d.2); *b)* overedge/Strobel (Elitech, n.d.); *c)* embroidery (Holiauma, n.d.)

Shoe: goat, n.d.

The polymer science and quickly adapting chemical industry produced quite several synthetic materials pretending to replace leather in the shoe constructions: nearly a dozen of "promising" poromerics and so called "artificial/synthetic leather" were developed in the mid of 20th century. They claimed to be comfortable (breathing) like leather, whereas they have uniform physical properties (width, thickness, elasticity, stretch etc.), whereas variable sizes/shapes, topography and thickness of leather are the major disadvantages making difficult to atomate shoe production. The thermoplastic feature of these materials opened the way for using *high-frequency (HF) welding* and it was hoped that this productive technology can eliminate stitching from shoe upper making. After very optimistic 10-20 years it has been realized that hygienic properties of these "artificial/synthetic leathers" could came achieve the leather provides. Quick fashion changes led to shorter orders and need for reducing the lead time in the production chain, costs associated with tooling requirements (for each sizes and new style) undermined the feasibility of HF welding in footwear manufacturing.

Beside sewing there are some operations performed in closing rooms that use *special machines* for [stitch] marking and stamping/numbering, edge folding, interlining/to-puff gluing/fusing, boot vamp preforming/moulding, eyeleting/riveting, lacing etc.

Shoe assembling

In this process the bottom (sole) construction is attached to the shoe upper. Quite many shoe constructions (i.e. methods of fixing bottom parts to the shoe upper – through the insole or directly) have been developed. They may be grouped as

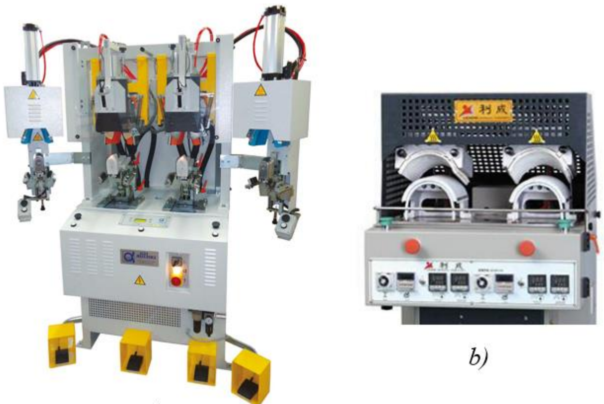
a) mechanical
- nailed (wood, screw, nail);
- sewn (Goodyear/Gosier welted, Blake/McKay, Veldtshoen/stitched down, polyveldt, cup sole/wall stitched, [tubular] moccasin, turned);

b) chemical
- cemented (stuck-on);
- direct (vulcanized, injection moulded);

c) combined.

Nailed shoes are old history. Stitching welts and soles (together with the related operations) makes shoe assembly labour intensive and expensive, so these constructions are used today only for certain types of footwear. The Goodyear welted, Blake sewn (and their combinations with cementing) are present in the market – mainly in the bespoke/exclusive and functional footwear –, but their share rather low (less than 5%).

Shoe uppers made of leather need to be *condition*ed by steam to facilitate forming them on shoe lasts. Earlier steam chambers were used for this purpose: the larger types had space for several hundred pairs and uppers were kept there for hours or even a complete day/overnight, the smaller ones accepted a few (maximum around a dozen) pairs for a couple minutes. By the acceleration of the production-trading cycle – especially with the implementation of the "Just-in-time" or "Quick-respond" principles – they have been replaced by back-part pre-moulding and toe-part conditioning machines (*Figure 30*). These equipment also activate (i.e. melt) stiffeners and toe-puffs.



a) *b)*

Figure 30. Shoe upper activation and pre-moulding
a) back-part (Brustia, n.d.); *b)* forepart (Made-in-China, n.d.2)

Forming shoe uppers on shoe lasts used to be one of the operations requiring well developed skills from manual workers. Modern *lasting* machines take over this a great deal of these tasks from humans and merge fazes of lasting: now one equipment performs pulling over and toe- and ball-part lasting, another the heel-seat and side/waste lasting, whereas machine operators are assisted by computer control of crucial elements of these operations (*Figure 31*). Pulling over and lasing machines have 5-11 hydraulically moved and electronically controlled pincers for grasping/holding and pulling the upper, wipers toggle the lasting margin over the insole (or to its lip/rib in Goodyear welted construction) and usually injected hotmelt (thermoplastic glue) fixes the lasting margin onto the insole. Fashion changes are reflected mainly in the shape of the toe-part of the shoe [last], therefore in modern pulling over and toe lasting machines computer controls the adjustment of pincers, their pulling forces, stores shoe last shape information. As the denomination suggests heel-seat and side lasting machines pull and fix lasting margins in the back-part (with tacks or hotmelt) and over the shank part (usually with hotmelt). Both these machines have hydraulic mechanisms, very complex constructions, efficiently automated movements freeing operators from physical efforts and decision making (i.e. the operation of these machines do not require extensive human skills). In most advance footwear manufacturing plants robots pick up shoes from the pulling over and lasting machine, move them to the heel-seat and side lasting machine then – after the operation is complete – move the fully lasted shoe to the next position (conveyer, intermediate storage, heat setter or the next operation/machine).

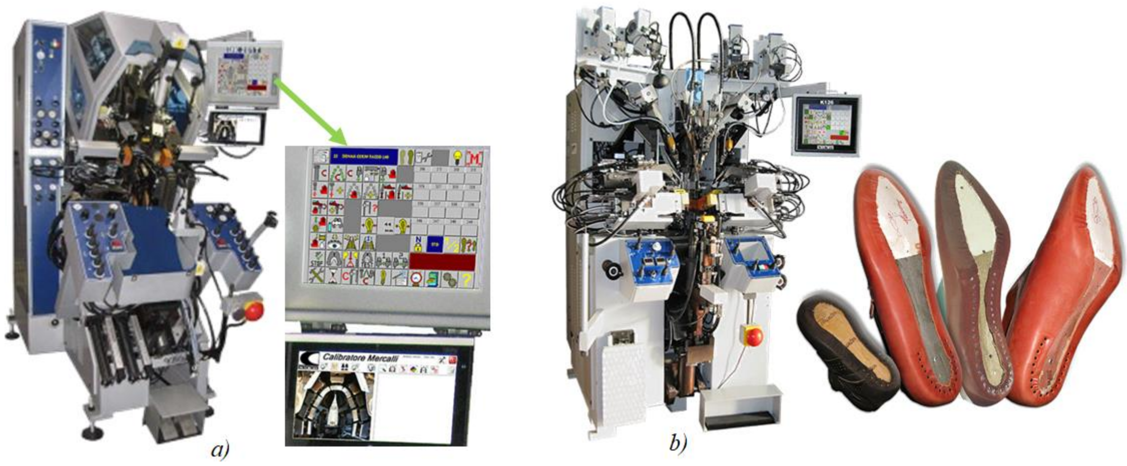


Figure 31. Lasting machines
a) pulling over and toe lasting (Cerim, n.d.1); *b)* heel-seat and side/waste lasting (Cerim, n.d.2)

As lasting is made by forming shoe uppers with pulling forces, tension is generated in the materials. In order to eliminate this tension and to achieve permanent deformation that will ensure form stability of finished shoes *form/heat setter*s are used. Usually these are tunnels in which lasted shoe uppers (of course, together with shoe lasts) are moved by a conveyor [belt] in an atmosphere of circulated air. The advanced devices may have a hot followed with a cold chambers, in addition to a vacuum for facilitating/speeding the decreasing the humidity of materials of the upper construction. Form/heat setters are also equipped with electronic control of the atmospheric conditions inside respective chambers and the vacuum.

To produce footwear of sewn shoe constructions *welt and/or sole sewing machines* are needed that are quite different from those used for shoe upper stitching/assembling. Welts in Goodyear and Goiser constructions are sewn to the lip of the insole through the upper's lasting margin with single thread chain stitch (*Figure 32*).

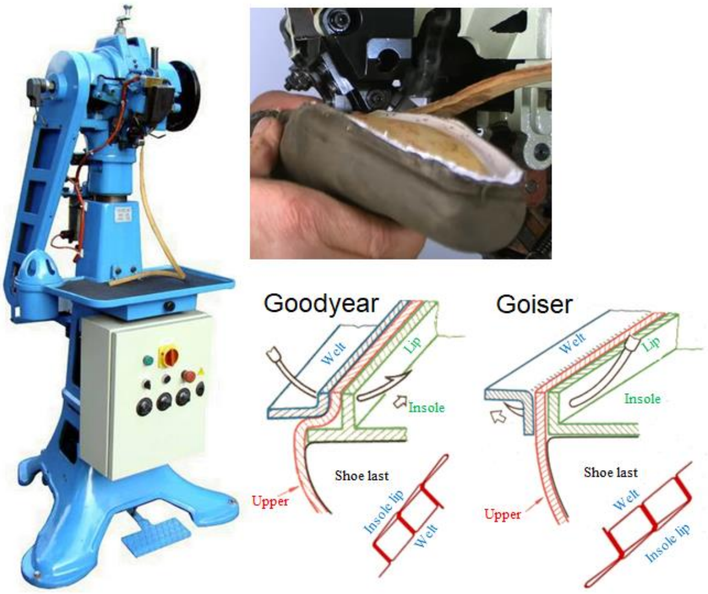


Figure 32: Welt stitching machine (Goodyear Welt Machinery n.d.)

In Goodyear, Goiser and welted Veldtshoen constructions inner and/or outsoles are sewn to the welt (in Veldtshoen through the edge of upper). These machines work with lockstitch. In Blake/McKay construction the sole is stitched to the insole (without the shoe last). Earlier Blake/McKay *sole stitching* machines worked with single thread chainstitch, modern versions work with lockstitch. The results of a relatively new development is the wall side sole stitching: here the shoe upper is sewn to the unit sole (*Figure 33*). Channels opened (mostly slanted) in leather soles are usually closed after the sole stitching operation, but in more and more cases vertically grooved channels remain opened to show the seam to customers (that suggest higher sole adhesion than that of only cemented to the lasting margin).

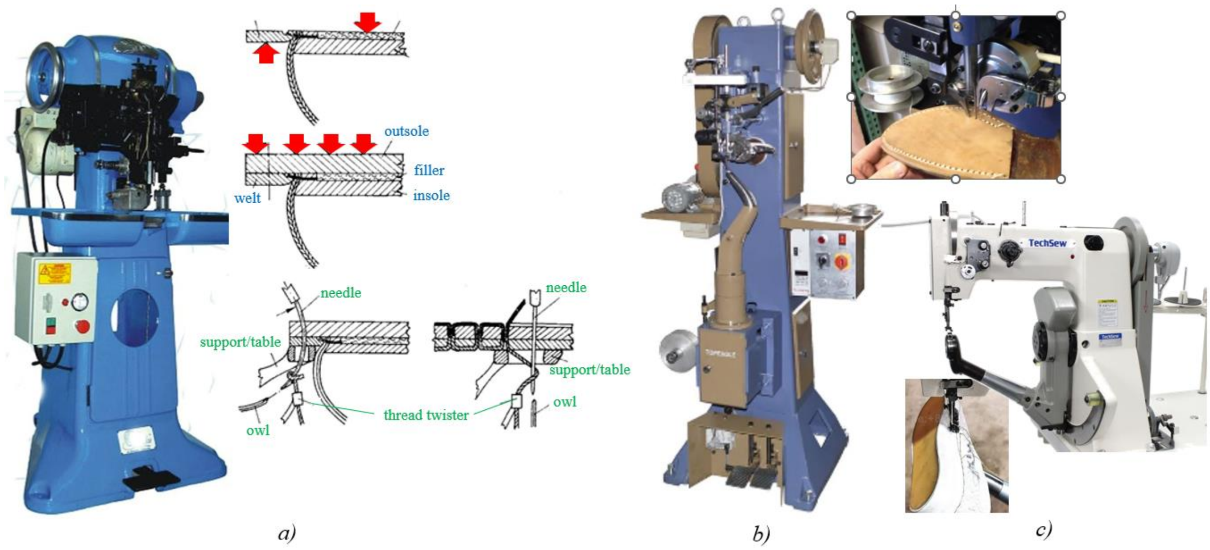


Figure 33. Sole stitching machines
a) Goodyear/Goiser (Good Year Machinery, n.d.); *b)* Blake/McKay (Topeagle, n.d.); *c)* side wall (Techsew, n.d.)

The working principle and the mechanical construction of welt and sole sewing machines have not changed during the 170 years of their existence. Due to the small share of sewn shoe constructions in the World total shoe production (because of their high production costs) the demand for these machine is rather limited, so radical innovations are not expected in this area.

Not only ancient shoes made by primitive men, also but those made up until the end of the 18th century were made of leather (or some uppers were made of textile), whereas the practically all parts/components, including the assembled upper and sole were fixed to each other by sewing. As vulcanization was invented and glues of various origin were developed shoemakers were look for adhesives that may replace the complicated welt and sole stitching. The first adhesive that provided sufficiently strong bonding was nitrocellulose based but it made the sole construction rather rigid, it was flammable and harmful to health, the time required for sole pressing was long (20-40 min). Nevertheless, it has been used from the beginning until mid of the 20th century. At the same time chloroprene, neoprene than poly-urethane adhesives were developed: they needed much less pressing time, made a flexible are strong bonding. Nowadays more and more water-based adhesives are used for cemented and direct soling constructions.

The majority of – especially everyday/street and ladies – footwear are made by cemented/stuck on technology. Mostly prefabricated and unit soles are attached to the lasted shoe upper (lasting margin) after activating the dried adhesive layer on both surfaces by heat (usually infrared lamps). The sole is attached (still by hand) to the lasted shoe upper and then put in the *sole press* (for 10-30 s). Depending on the shoe last shape (heel height) and the sole (normal or walled) different sole press and pad constructions may be used (*Figure 34*). As a consequence of activation soles may be still worm, so chilling tunnels (similar to heat setters just shorter and applying air of low temperature) may need to be used that also stabilize bonding.

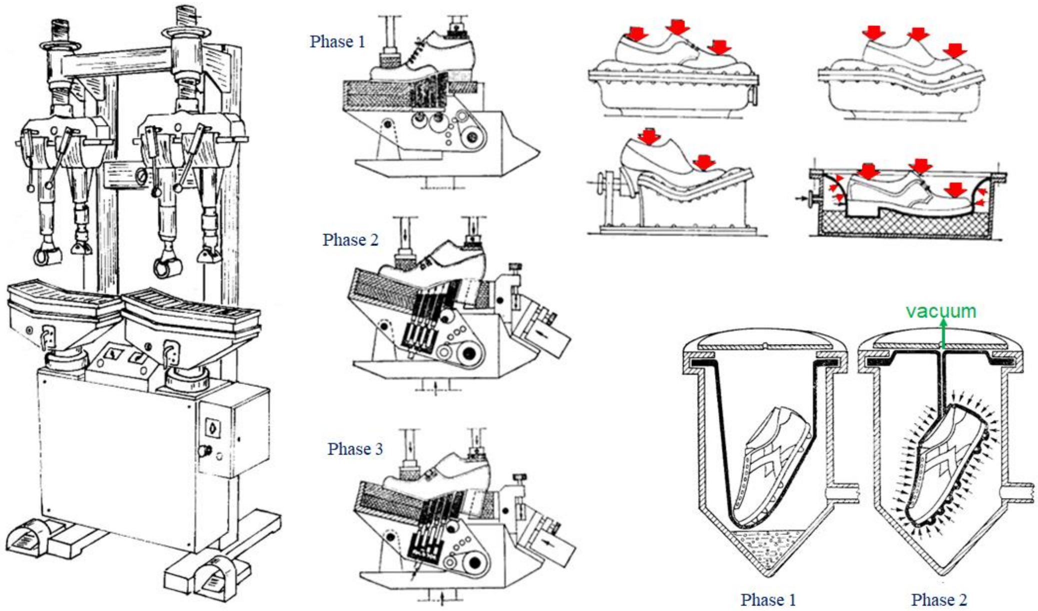


Figure 34. Sole press architecture and pad variants (Beke, 1981)

Moulding full shoes (galoshes and boots), as well as soles/heels on lasted shoe upper became a real possibility when rubber was invented. For a long time rubber appeared to be an effective substitute to leather soles, which could be formed right on the lasted shoe upper: in fact it was the first direct soling method used in footwear manufacturing. *Direct vulcanization* is still being used for heavier types of footwear (e.g. safety and military boots). However, rubber processing is a complex technology requiring heavy and expensive equipment, so from early 1900s serious efforts have been made for replacing leather/rubber with plastics, that resulted in PVC, TR, PU and EVA (granulates or compounds), which can be injected onto the lasted shoe. Direct *injection moulding* machines have a (usually) carousel holding the 8-64 moulds that – together with the lasted shoe – form the cavity of the sole (*Figure 35*). Modern machines may have more than one injector (for multicolor or multidensity) soles. Apart of the high investments injection moulding requires fairly costly metallic moulds for each style and shoe size that hinders the feasibility of applying this technology in small- and medium scale operations.

Figure 35: Shoe sole direct injection moulding machine (Desma, n.d.)

Relatively simple machines are used for finishing shoes (e.g. attaching heels, polishing, spraying): in this area only very limited innovation has been achieved.

Technology of making certain types of footwear has changed radically. Many of athletic/sport shoes (sneakers) and some functional footwear have no leather in their construction at all. For instance the production process and equipment used in of ski boots manufacturing – apart from their lining – show more similarity with metalworking than footwear.

Other leather products manufacturing

Cutting and sewing machines used in making leather goods, gloves, leather garment and upholstery work on the same principles and supplied by the same machine manufactures as those used in footwear manufacturing: they defer mainly by their sizes and maybe in certain parts.

Historically leather was the first material used for covering the human body (not only feet), but soon textiles became the most widely used material for garment. Nevertheless, *leather garment* has been used for specific purposes (e.g. safety, sports) and appeared as a fashion trend in the 20th century. The technological process of making leather garment is practically the same as in case of textile clothing – the only major difference is cutting where properties of leather (e.g. size, topography, thickness, possible faults) require special attention/knowledge. Otherwise cutting of leather garment components is mainly made manually by using large scissors, whereas die cutting may be used only when the garment/components are composed of small pieces – but not always. Sewing machines used for textile garment (including those for making button holes) are suitable for stitching leather garment as well. Finishing contains also similar operations with the exemption of pressing and folding.

Thanks to their different functions the share of leather substitutes used in *leather goods* ([hand]bags/cases, small/flat goods, belts etc.) is higher than in footwear. Nevertheless, leather remain an important basic materials for these commodities. The production technology implemented in leather goods (especially soft constructions) making shows strong similarity of cutting and making shoe uppers as far as applied tools and [heavy sewing] machines are concerned. There are special sewing machines for making luggage and bags (*Figure 36*). The only radical development took place in large(er) and hard travel goods manufacturing. Originally the widely used travel trunks were made of vegetable leather, later also of vulcanized fiber by stitching and/or riveting. As travel habits has changed and new materials (plastics) appeared they were replaced by suitcases that are very popular and sold in different sizes. Cutting of the sheet materials for suitcase covers is now replaced by vacuum [thermo]forming (*Figure 37*) of polycarbonate (PC), polypropylene, acrylonitrile butadiene styrene (ABS) etc., whereas linings are assembled by stitching, frames may be stitched or riveted.

a) *b)* *c)*

Figure 36: Luggage/[hand]bag sewing machines
a) arm type (Dongguan Jianglong Intelligent Technology Co., Ltd. n.d.); *b)* post-bed (Techsew, n.d.); *c)* movable post-bed (Great Rich n.d.)

Figure 37. Luggage vacuum forming machine (Alibaba, n.d.5.)

Leather *gloves* had been made manually for centuries. The invention of the sewing machine motivated the construction of the two key machines used in – not only leather – glove manufacturing (*Figure 38*). Conventional leather sewing machines are used in production of workers gloves made of crust and split leathers.

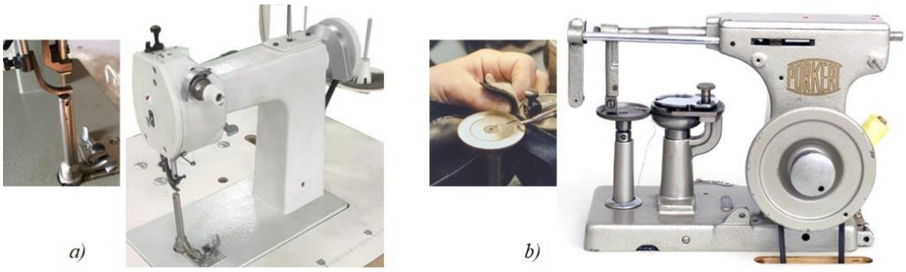


Figure 38. Glove sewing machines
a) double chain (Alibaba, n.d.4); *b)* Prixseam (Hauser+Renner, n.d.)

Leather *upholstery* was traditionally used for furniture. As flying and automobiles become popular, more and more specially finished leather are used for covering seats of passenger airplane and car seats. Equipment use for cutting large full hides and assembling seat covers are very similar to those used in footwear and leather goods manufacturing.

Auxiliary equipment

Beside production machines designed or adapted for performing designated operations in the leather value chain there are equipment that serve or support the production processes (e.g. internal transport, maintenance) or ensure safe working conditions (e.g. dust/fume exhausters). Many of them are of general purpose and used in other industries as well (e.g. fork wheels, robots).

Soon after Ford introduced the *conveyor* belt in car manufacturing/assembling in 1915, the idea was adopted in other – including leather products – industries as well. In shoe manufacturing the continuously moving conveyer not only moved workpieces between workplaces performing distinct operations (manually or by machines), but also dictated the temp at which workers had to complete their operations. While styles were produced in large quantities and the sequence of operation was constant conveyers contributed to increasing/maintaining productivity of the whole process. Accelerating fashion changes influenced the sets and sequences operations that needed to be changed when new styles were introduced, so machines and workplaces had to be rearranged along/around conveyers for which the production was stopped. New types of conveyers (e.g. direct delivery, duo-rail) were constructed, computer control was introduced for increasing the flexibility of production processes. When the mass outsourcing waive relocated a great deal of footwear production [predominantly] to South-East Asia by end 1900s the new version of the belt conveyer: all thermos-reactive processes are performed by respective (e.g. pre-heating, adhesive activation, heat setting, drying) equipment built over the moving wide belt (*Figure 39*).

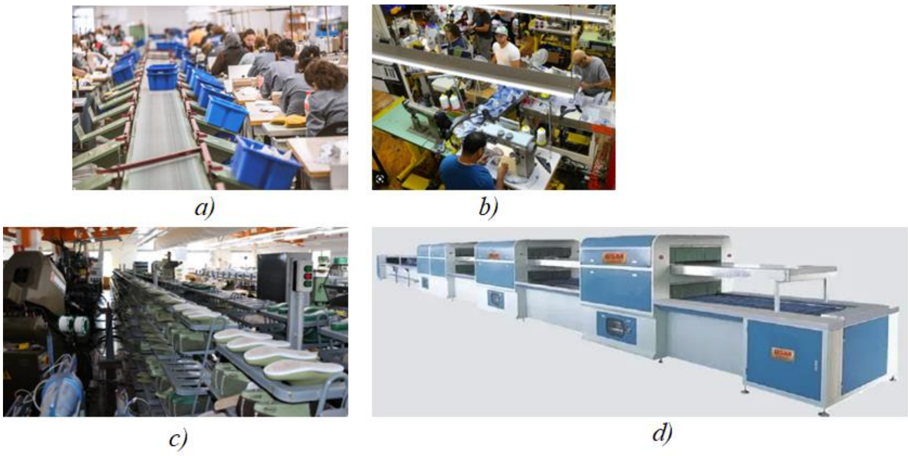


Figure 39: Conveyers in shoe production
a) direct delivery; *b)* rink system; *c)* assembling; *d)* new belt line

In many shoe factories discontinued the use of conveyers, instead implemented so-called *rink systems* based on operating several different machines into small groups/isles in which operators decide how to distribute tasks and will move to the particular machine needed for the actual operation. Development of footwear technology made also possible to merge operations carried out manually or by separate machines and to build respective equipment (e.g. profile splitting, heel-seat and side lasting, roughing and dedusting) that also removed the need for transporting workpieces between operations/machines. All these lead to eliminating conveyers from production lines. However, (e.g. overhead) transporting conveyors remain valuable

Robots are new players in the leather-based industries: they are used primarily for replacing human work. Some robots are used today for loading/unloading (especially through feed type) tannery equipment. Their application is somewhat more intensive in footwear manufacturing (e.g. moving workpieces between lasting machines, roughing and applying adhesives on shoe lasting margins and [unit] soles, spraying release agents onto injection moulds).

Both tanneries and leather products manufacturers (especially medium and large factories) have quality assurance system supported by their own *testing laboratories*. Some of testing equipment are of general purpose: they are used in other industries as well (e.g. tensile tester, pH-meter, Martindale and Shopper types of abrasion tester, viscosimeter). There are testing equipment specifically designed for leather and products made of leather and its substitutes. These include the Bally flexometer, the Bally penetrometer, the lastometer, the Desma sole adhesion tester, the Bennenwart sole flexing machine, the adhesion of finish tester, the water-vapour permeability apparatus. The development in this area is governed by adding electronic and/or computer control to the testing process.

Future trends

- Thanks to the development of the chemical science and technology the share of leather substitutes in shoe and other leather products constructions continue to grow. However, *leather remains* the preferred basic material in certain types of products featuring foot comfort and prestige. Moreover, a great deal of products made of leather substitutes (e.g. textiles, poromerics, plastics) are produced by using traditional technologies and machinery.

- More and more *operations will be merged*, whereas will be eliminated by using intelligent materials for reducing human interventions, improving reliability and increasing productivity. This will be followed by combining respective machines.
- *Automation* will continue with special references to applying electronic and computer control, CAD/CAM and robots. The aim is the computer integrated manufacturing (CIM) and global networking.
- Technologies and production systems will be more *flexible* to meet customers' expectations, which will employ versatile, easily adaptable equipment.
- The governing principle in developing equipment for leather processing and its derived products manufacturing will be *sustainability*. New machines will use less energy, produce less wastes, they will be lighter and recyclable.

Conclusions

1. The basic principles of processing hides/skins into leather, as well as making leather products have not really changed during the history of these industries.
2. Leather processing and its derived products manufacturing remain(ed) entirely different technologies using very different equipment, whereas a significant share of machines used in leather products (footwear, leather goods, gloves and leather garment) are very similar or exactly the same.
3. Introduction of new materials (e.g. enzymes for dehairing, chrome alternatives for tanning, rubber and leatherboard for footwear and leather goods, synthetic threads and adhesives) has not changed the working principles and construction of production equipment (i.e. the same vessels, cutting and sewing, sole attaching etc. machines could be used or just minor adjustments were needed in their settings). The only radical changes took place when thermoplastic materials made possible to introduce direct injection moulding of soles and vacuum forming of hard bodies travel goods.
4. The closing room remained the most labour intensive phase in footwear manufacturing: this is the main reason why the shoe upper manufacturing was the first in outsourcing and still widely practiced.
5. Bespoke and orthopedic shoes are claimed to be "hand-made" whereas more and more machines are used in their production.
6. Glove making benefited the least from mechanization of production processes – let alone its automation.
7. Future development in mechanization and automation of leather processing and leather products manufacturing – as earlier – will depend on achievements in other industries. In other word, the likelihood of inventing new technology in the leather-based trade first and taking it over by other area of manufacturing remains fairly low.

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Remark: n.d. = no date