Modeling the Process of the Development of Loading Units

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This book shows how the load unit was created, and how it changed from the simplest basket to the modern metal container. A model of the stages of change of the load unit is presented, and the reasons for the changes and a possible new path of development are indicated.

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1

INTRODUCTION

From the moment Homo Sapiens began to form human groups in which the division of labor began, there was a need to move things that were personal property or food. We know from archaeological research that the hunter-gatherer lifestyle of our ancestors was the reason for the desire to explore the environment in order to obtain food. Thus, movement in search of food was the reason for the creation of cargo units.

Means of transportation – a technical solution that enables the movement of people and goods in the surrounding physical environment, land, water or air. Means of transportation were created to reduce the amount of labor and energy needed to move people and goods. The loading units relate to the possibilities of transportation by means of transportation. The use of means of transport adapted for movement in a physical environment defines the so-called branch means of transport. The main technical means of transport are inland and sea vessels, land vehicles, road and rail vehicles, and airplanes.

1.1. Phase and development

Phase in a deterministic mathematical model is the state of an object or signal at a given time. A common description refers to electrical, pneumatic, and light signals.

Development is defined as a change from the previous state in a given time interval. The common slogan of development refers to the nature of plants and animals of man, Darwin's theory of evolution. It also applies to technical progress or the scope of application of a given technique or technology, for example, a change in the density of the railroad network.

No publication would describe the stages of development of the loading units. So far, the place of the loading unit in the transport and storage system has been described by a graphic model. However, the challenge is to show what has influenced the change in the loading units used in the past and to describe it with a model that allows predicting the future of loading unit changes.

1.2. Review of the literature

The basic question refers to the title Modeling, the development process of load unit phases.

A model, according to the definition, is the word “model”, which was created from the Latin word “modus” – “modulate”, which means: measure, image, way. Its original meaning was associated with the construction and was used to designate a pattern or an object similar to another object [70], [205].

The procedures of the scientific research and its verification by the experiment, described in the literature, show that the term “model” is used in two different senses, namely, to denote a theory that is structured [478]:

- to denote a theory that is structurally similar to another, which makes it possible to pass from one theory to another with the help of a simple change of terminology; in this sense, a model is a means of cognition;
- to denote a system to which a practical or theoretical theory refers for a simplified reflection of the natural system under study; such a model is an object of knowledge.

A model is a real or imaginary image that replaces the studied natural system (atom, molecule, mechanism, solar system, etc.). This image reflects specific, real or hypothetical properties of the studied system and its structure and is similar to the structural peculiarities selected by the researcher. The elements and relations occurring in the modeled system are reflected in other elements and relations typical for a given field of research.

Therefore, the model is a kind of idealization or simplification of reality. The type and degree of simplification depend on the researcher’s knowledge, needs, and awareness, and may vary depending on the purpose of the research. What theory and model have in common is that they refer to reality in a simplified, abstract form.

A formalized description in which they are precisely defined: composition, structure, input elements, and rules of transformation become synonymous with quantitative notation, the natural system under study. When we identify a formalized description with an experimentally confirmed reality, we obtain a logical-mathematical or mathematical model that reflects the object, phenomenon, or situation under study. In technical and economic sciences, this model is increasingly used to simulate the functioning of the system that the model reflects [485].

Other definitions of models indicate that the model is

- it is a conceivable or materially realizable system which, by reflecting or reproducing the object of study, is capable of substituting for it, so that its study provides us with new information about that object [404];
- representation of the phenomenon under study in a form other than that in which it occurs in reality [90];
- is understood as a representation of the phenomenon under study, i.e. a substitute for reality, deliberately simplified, treated piecemeal, omitting irrelevant details and features [202];
- a physical or abstract structure (system) whose degree of similarity to the modeled system makes the study of the model provide information about the system in question that is relevant and useful for research [356];
- a simplified representation of reality or its fragment on another material basis, capturing those features of the system that are important from the point of view of conducting research [156].

Models, as products of the human mind, are classified by the definitions and functions performed by the model. Thus, the model is defined as follows.

1) A model is understood as a conceivable or materially realizable system that, by reflecting or reproducing the object of study, is capable of stopping it so that its study provides us with new knowledge about this object [85];
2) A model is a tool that can be used to describe a system and its behavior under various external conditions [50];
3) The model is a theoretical description of the study of objects, which is characterized by the following features, i.e. [51]

- a certain simplification of reality;
- in the sense of a specific criterion that coincides with reality;
- so simple that it is possible to analyze it with the available computational methods;
- a source of information about the object of study.

The construction of models is carried out by a scientific discipline called identification [50], The classification of models allows us to determine how the modeling method depends on the purpose of the research and the specifics of the system under study. Classification is the basis for determining the essential functions performed by models, namely:

- the practical function that models perform as objects of scientific knowledge;
- the theoretical function that models perform as a particular image of reality, uniting logical and intuitive, concrete and abstract, and general and detailed elements.

When beginning to create a model, one should

- determine the purpose of modeling, the associated requirements, and the means to build the model;
- determine – which segment, which system should reflect the model.

There are several kinds of models [298]:
Model – a material system (e.g., a mock-up) or an abstract system (e.g., drawings, verbal descriptions, mathematical equations).

- physical model (nominal) – description of processes in the object (physical, including economic and social).
- mathematical model – a set of rules and dependencies, based on which the course of the modeled process can be predicted using calculations. A mathematical model is an equation describing the process and any relations describing constraints and simplifications (for example, inequality).

Also distinguished [622]:

- conceptual systems: vague ideas, conceptions, values, mental models (e.g., ideas, definitions, solutions, attributes specified in the designer's mind).
- fuzzy systems: systems with defined but not fully measurable attributes (e.g., bioenergy).
- structured systems: fully defined in terms of structure, relationships, and functions performed (technical systems).

In general, models are created through a theoretical assumption, a description of reality, or the establishment of a cause-and-effect relationship.

Thus, descriptive models are those [622] in which the behavior of the object of study is described, and the behavior is attempted to be imitated. On the basis of behavioral observation, a mathematical model is created, which may be unrelated to the structure and processes occurring in the actual system. It is used in regular and repeatable processes with unchanged conditions and parameters. Thus, its advantage is simplicity, speed, and ease of simulation.

More advanced are causal models [622], in which the behavior of the object of study is explained, and the structure is attempted to be reflected. Based on the elements of the system and their interactions, a mathematical model can be created that reflects the essential structure of the system (elements and interactions). It is applicable in systems with feedback and complex interactions, nonlinearities and bifurcations, with changes in conditions and parameters. Thus, these models have very reliable prediction results.

These main types of models are further divided into subcategories [485]. For example, material models reproduce exploitation systems and the processes taking place in them by means of geometric similarity (e.g. mock-ups, cross-sections, plastic systems, prototypes) and physical similarity (e.g. kinematics, dynamics, thermodynamics). It is this geometric scale that is used. Physical models are different in that they are smaller-scale devices in which the same physical process takes place as in the real object. They are designed to study specific fundamental processes that occur in a real object.

All models can be classified into [60]:

- theoretical,
- material.

Theoretical models can be divided into:

- intuitive,
- formalized.

Intuitive (subjective) models of operation processes of technical facilities are created on the basis of statements of individual specialists and collective expertise developed by voting, panel discussions or the Delphi method.

Examples of intuitive models can be algorithms, setting deadlines for servicing technical equipment, changing lubricants, and changing the state of objects using organoleptic methods (e.g. visual, auditory, tactile).

Formalized models are a representation of physical models at an even higher level of abstraction. Such a representation can be created when mathematical or logical signs and relations can express the concepts in the physical model. A feature of the formalized model is the complete lack of similarity between the elements and relationships from which it is built and the composition and structure of the system being modeled. The model is conventional, not illustrative, and has nothing to do with the nature of the elements and relationships that make up the modeled system [205]. They are divided into:

- analog,
- symbolic.

An analog model of the operating system of technical devices and the processes taking place in it is described by other physical quantities, for example

- Mechanical force is added by electric voltage;
- Speed corresponds to the intensity of the electric current;
- Displacement corresponds to electric charge.

According to these fundamental quantities, other equivalents are determined, e.g. mechanical power – which is the product of force and velocity – is equal to the product of voltage and current, i.e. electrical power. Dimensional analysis can be used to determine the equivalents of other quantities, such as mechanical inertia, mechanical work, and elasticity [274].

Symbolic models are classified as [320]:

- verbal – otherwise descriptive (for example, instructions for the use and operation of all-terrain vehicles);
- graphic – representing an object, phenomenon, or process using graphic symbols (e.g., a diagram of the electrical installation of a tracked vehicle);
- mathematical – through the process of conducting some cognitive research, the result of which is a mathematical model of a fixed real object, taking into account the problem associated with it and the goals of modeling [410], which reflect the processes of use of technical objects using symbols, equations and mathematical inequalities, logical relations (relations). It should be emphasized that the formalized model is almost always the result of the

assumptions and judgments of the expert who built it. Such a model cannot be completely objective [320].

There is no recipe for a good model. Often, several models of different structure and complexity are developed, and then the most practical is chosen. Knowledge of the laws governing the phenomena, experimental data, and other information should allow us to determine the structure of the model, i.e., the forms of relationships that we believe will adequately express the relationships between variables. Modelling is the totality of activities aimed at creating a physical and mathematical model consisting in selecting a substitute called a model for the original, mapping the studied reality or its fragment, and then experimenting with this model [156].

A review of the literature indicates that the [814] phase is

- the state of the process or development of the phenomenon at a given moment,
- a part of a physical system with clear boundaries at which certain physical or chemical properties of the system undergo a step change,
- the state of a periodic phenomenon at a given moment.

Furthermore, evolution is [815]:

- the process of passing into more complex or, in some respects, more perfect states or forms,
- as events evolve over time,

But also [754]:

1) any long-term process of directional change in which the successive stages of transformation (developmental phases) of a given object (system) can be correctly distinguished, showing an ascertainable differentiation of this object in a specific respect;
2) the process of directional transformations in the course of which objects (systems) of a given kind pass from simpler, lower, less perfect forms or states to more complex, higher, more perfect forms or states in a given respect; The concept of development, understood in this way is closely related to the concept of progress, especially in everyday speech and in older scientific literature.

Development is when there is a qualitative change and a transition from an existing situation to a better, more perfect and desirable situation [326].

Kornel Kwiatek presented a detailed analysis of the idea of development in economic terms. He distinguished five main ideas of the essence of the concept of development of the economy (economic growth, economic development, socio-economic development, sustainable development), and as the last one – he indicated the economics of development. In conclusion, he pointed out that development economics have come over a long way in its evolution, according to the old saying: “deeper into the forest, the more trees” [206]. The more thoroughly we investigate, the more doubts we find and the more answers we seek.

The process is [356]:

- the course, development, transformation of something,
- sequences of elementary changes in the state of a fragment of reality occurring in time,
- The values of measures of all attributes and relations between elements are called the state of the system, the process can be defined as a sequence of changes in system states, ordered over time.

The loading unit is an element of man’s transport and storage system for economic purposes. Thus, it is part of the manufactured anthropotechnical system. The design creates a system as a logical basis for action [70]. An anthropotechnical system is a complex relationship between a human being and a technical means, resulting from the conscious interaction of the human being with the technical means. This relationship has spatial, temporal, and functional dimensions [458].

Connection is the interdependence of man and machine, understood as the relationship between the subject and the tool (environment) of work. Every technical object controlled by man constitutes a system of action, and every system of action used by man can be treated as an anthropotechnical system [380].

Man has designed the transport and storage system. The loading unit was designed to facilitate the movement of the selected goods in order to save human labor, reduce costs, and satisfy needs.

Therefore, it makes sense to analyze this relationship in the context of the anthropotechnical system approach and its model description.

2

UNIT LOADS AND HISTORICAL DEVELOPMENT OF INTERMODAL TRANSPORTATION

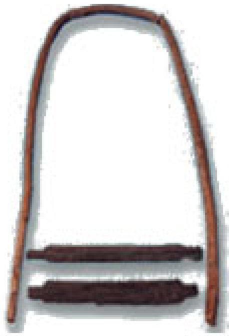
2.1. Load units made from the bark and skin of trees

Data from archaeological excavations prove that the first packaging made in Africa and Asia in the Paleolithic period was made from natural raw materials: animal skins, bark, plant phloem, reeds, grasses, leaves and shoots of trees and shrubs. They were woven into mats and fabrics to make bags, sheets, scarves and containers.

The first container used by man could be a piece of bark or skin of a hunted or dead animal. These containers were made for their own use. The movement of prehistoric people created the need for packaging to carry food and probably to carry embers to light fires. As lifestyles changed from hunter-gatherer to sedentary, more durable containers were made. Direct evidence for the use of bark and leather containers are objects found by archaeologists at Ötzia – the Iceman [764]. This nickname was given to the remains of a man (found in a glacier in South Tyrol) who died around 3300 BC [640]. He was carrying two birch bark containers and a frame, probably a backpack. One container contained spruce and juniper needles and pieces of charcoal from a birch hub – birch pork (lat. Piptoporusbetulinus). Therefore, it was assumed that it was used to transfer embers. The second container was empty and clean inside, so it was probably used to transport food. Only traces of birch tar were found on it, which may indicate that this substance was used as a sealing material (Fig. 1). Ötzi's backpack was reconstructed on the basis of a nearly two-meter-high hazel stick, bent into a U-shape with two narrow wooden slats. Pieces of leather and hair preserved on it suggest that a leather pouch was attached to it (Fig. 2) [639].

The type of leather containers used for transportation were wineskins – bag-shaped containers used to transport water, wine or milk. Evidence of the use of wineskins are bas-reliefs from archaeological excavations (Figs. 3 and 4).

1. Birch bark container of the Iceman – Öetzi, from 3300 BC [639]



2. Backpack frame of the Iceman – Ötzi, from 3300 BC [639]

3. Fragment of relief with the hand of a Nubian with a leather bladder from the collection of The Metropolitan Museum of Art from San Francisco (USA), dated 1961-1917 BC [690]

4. Fragment of the relief from Persepolis, dated to the years 550-330 BC [840]

2.2. Braided Load Units

Weaving developed in Africa and spread to temperate climates. It consisted of weaving from various types of raw materials, such as grass, leaves, roots, straw, shoots of trees and shrubs, plant fibers or strips of leather, elements of clothing (footwear, loincloths), and elements used in construction or for everyday use.

The straight cross-weave could be made by mapping a grid from a dried leaf or bark of a date palm (Fig. 5) or coconut palm (Fig. 6). This suggests the possibility that the ability to weave existed before the emigration from Africa, 130,000 BC [author's note]. In Europe, the typical raw materials used for weaving were roots, wicker, birch branches and hazel. In 2011, in Sibudu, South Africa, a 77,000-year-old habitat of prehistoric people was found with the remains of mattresses woven from the leaves of the Cryptocaryawoodii tree [435] (Fig. 7.), which are naturally impregnated with an insecticidal substance and suitable for repelling mosquitoes [743].

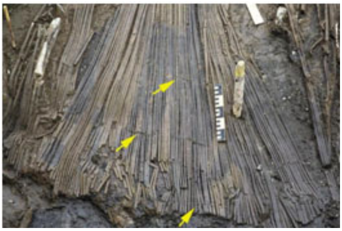
Evidence from Africa (Fig. 7.) indicates that this plaiting has a single source of origin in three subcontinents and is identical. It is confirmed by the analysis of baskets used by the longest isolated aboriginal civilizations of Australia [280] and in archaeological finds (Figs. 8-11), currently observed among the Air tribes living in a hunter-gatherer mode [839] (outside the modern economic system, author's note) in the forests of South America [472], or on the island of North Sentinel in the Indian Ocean [290], also in New Guinea [654]. They were made using a straight cross-weave. The skill of basket weaving allowed the development of the production of cloth and the construction of, for example, houses, animal traps, and means of transportation. The ability to make meaning of transportation from local raw materials, such as reeds, allowed modern man to successfully colonize Europe, Asia, Australia, and both continents of the Americas.

It is probable that the transport container was created before the first departure of modern man from Africa, i.e. About 150,000 years BC [author's note]. Thus, the genesis of the creation of cargo units is contained in the original mode of hunter-gatherer life of the ancestors of modern man.

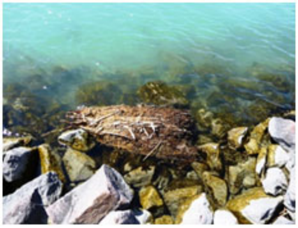
5. Scanning of the bark of the date stain tree. You can see the lattice structure

6. Looking through a coconut leaf. You can see the lattice structure.

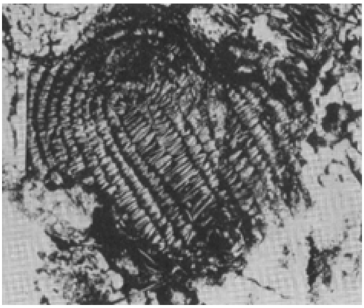
7. A Cut through layers from 58 thousand years ago with traces of burnt mattresses in Sibud. The black bands are charred stems and leaves, and the white bands are ash [435]



8. A trap made of branches and wicker from 7.5 thousand years ago was found in Russia [772]



9. Pot on the pier in Siófok on Lake Balaton, Hungary



10. Fragment of a wicker basket from a shipwreck found near Cape Gelidonya, III thousand BC [109]

11. Fragment of a basket from the second thousand BC in the Museum de Sito Chan Chan in Trujillo, Peru

Man, who moved around, used the already-known technology of weaving. In 2012, in southern Sweden, in the Skåne region, at the bottom of the prehistoric valley of the Verke River, flooded by the sea 9,000 years ago, at a depth of 5 to 12 m, archaeologists discovered the remains of seven fish traps in the form of baskets woven from hazel poles about the thickness of a human finger [379]. In December 2011, at the Zamostoye 2 site on the Dubna River near Moscow, archaeologists unearthed two large, perfectly preserved wooden fish traps (a type of woven basket made of pine branches) dating back 7,500 years (Fig. 8). Some of them still had bindings made of ropes of plant fibers [772]. It is a so-called pot, i.e. a woven fish trap (Fig. 9).

It indicates progress in the development of skills in the production of materials for transport packaging (Fig. 12) and the construction of huts. Due to the ephemeral nature of these materials, there are few archaeological finds of such containers (Fig. 13). Other sources of their use are described in ancient literature and images (Fig. 16). They testify to the universality of their use in both hunter-gatherer and sedentary lifestyles. The basket is a light and durable package for transportation and storage. Primitive man would not have used heavy packaging that would have hindered his journey. It is worth remembering that obtaining plant material for a basket was safer than hunting. Wickerwork has a wide range of applications. For example, they were used to make defensive entrenchments for cannons – fortifications of related wicker branches (i.e., fascine) filled with earth were used to strengthen the fortifications (Figs. 14 and 15).

The basket was also the first collective packaging used in transportation.

From 22 November 1830, Englishman Thomas Pickford began to develop the organization of the collection and distribution of goods for the Liverpool & Manchester Railway Company, delivering goods between London, Liverpool and Manchester. In the summer of 1831, he started special trains to the Newton Races. He gradually extended the network to Coventry, Birmingham, Oxford and Great Junction [375].

On 22 November 1840, Pickford introduced small packages weighing a maximum of 112 pounds (about 50.8 kilograms), packed in large containers or baskets with a wicker weave, capable of holding 8 hundredweight and 3 quarters (about 440 kilograms). From 24 November 1840, he began carrying parcels between Manchester and Birmingham (Fig. 17) [375].

12. Baskets in the marketplace of Caraz, Peru. It can see baskets with straight and hexagonal cross weave

13. A basket made of reeds and acacia branches in the Egyptian Museum in Cairo, from the tomb of Pharaoh Tutankhamun, 1333-1323 BC.

14. Reconstructed cannon position from 1552 with wicker fascine, Eger, Hungary

15. Fascine and siege ladder in the fortress in Kamianets-Podilskyi, Ukraine

16. Llamas with a load in baskets from 1671 [271]

17. Basket handling, *hampers*, at the railway station and parcel sorting *parcels* [734]

2.3. Clay vessels

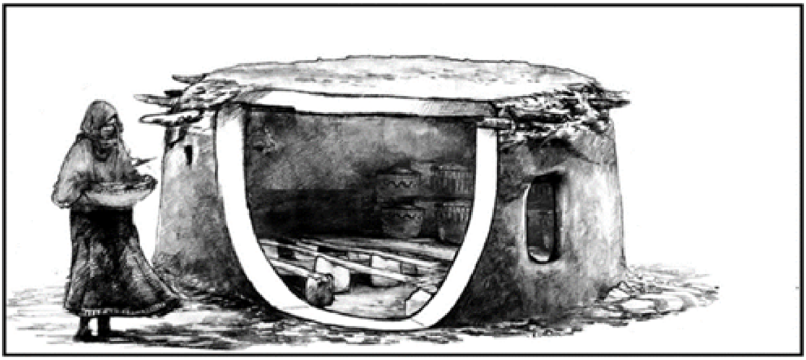
Fire was one of the most important discoveries in human history. There is evidence that it was first used over 1 million years ago [397].

There is evidence that the fish was cooked as early as 780,000 BC [483], probably in a vessel that has not yet been found. The thermal processing of food had an impact on human biology and the development of social relationships – the home. In the final period of the last glaciation of the Paleolithic period (i.e. about 40-14 thousand years BC [465]), due to the climatic conditions of the time and the frequent food shortages caused by the adoption of a sedentary lifestyle and thus the lack of access to new hunting grounds, man began to use ceramic vessels not only for preparing a hot meal, but also for storing food reserves. The ability to make and use dishes to prepare meals became widespread in hunter-gatherer communities before humans learned to cultivate the land and raise animals. Cooking food allowed people to make better use of the energy value of food. Previous studies suggest that the beginnings of agriculture are associated with climate cooling. The oldest ceramic vessel in the Xianrendong cave in southeastern China dates back 20,000 years (Fig. 18) [159]. Perhaps, the cooking utensils were in the form of a bowl, similar to those of the Japanese Neolithic culture Jōmon (12,000 BC to 300 A.D.) (Fig. 19) [419] and the Trypol culture (4200-2750 BC) (Fig. 20).

18. Fragment of a 20,000-year-old vessel from the Xianrendong Cave in China [159]

19. Japanese cooking bowl, Jōmon culture, dated to 10-8 thousand years BC [428]

20. A vessel with the decoration of the Trypol culture, dated to 4200-2750 BC, in the Wiśniowiecki and Mniszchów sites in Wiśniowiec, Ukraine.


21. Reconstruction of the Dhra grain storehouse (10,500 BC) in the Jordan Valley [201]

Initially, goods were transported to human settlements on the backs of people and pack animals. Natural waterways carried large flows of goods. Permanent settlements arose in connection with agriculture and animal husbandry. The oldest grain storehouses in the world have been found in the Jordan Valley. They come from a Neolithic village dating from about 10,500 BC. The freestanding granary had dimensions of 3×3×1,3 m (Fig. 21) [201]. When people began to establish permanent settlements around 7,000 BC and changed their way of life from hunter-gatherers to farmers, they already had a more stable source of food from crops and livestock. This allowed for a production surplus and became the first form of trade, the so-called natural currency. When the first ancient civilizations emerged, the first measurement systems appeared, designed to collect tribute and taxes for the rulers in a given area. The scope of the measurement system expanded as the dominant zone of influence expanded. The measuring system was translated into the dimension of income and expenses and transport packaging used in ordinary life. The volume of loose bodies and liquids was measured by the volume of the containers in which they were stored.

Ceramic vessels used for transportation are called, unlike ceramic cookware intended for cooking and packaging and should be combined with information about structured trade conducted by a man. The scale of trade created a demand for new means of transportation, handling systems and packaging. According to current research, the oldest data on ceramic packaging come from the ancient Near and Far Eastern states. In China, in the city of Banpo, one of the oldest forms of ceramic amphora was found, dating back to 4.8 kyr BC, used by the people of the Yangshao culture (Fig. 22) [512].

Archaeologists hypothesize that trade occurred both by sea along the coast of Asia and by land. Newly discovered artifacts continue to confirm this hypothesis. These consist of remnants of both transportation containers and packaging materials. The use of ceramic vessels in transport was most widespread between 2500 BC and 1500 AD. Archaeological research reveals that, from about 3500 BC, the Sumerians engaged in lively trade, exchanging goods using boats that were more capacious than the ox-drawn carts previously known. During the reign of Sargon I (2340-2315 BC), contacts were reignited. Trade was conducted with Dilmun (Bahrain), Magan (Egypt?), Meluha (Ethiopia?), and India, as evidenced by the reliefs at Nimrud. People of the ancient Indus Valley civilization travelled to present-day Oman, Egypt, and Mesopotamia. Mummified Egyptian and Assyrian corpses were found at Lothal, India. Broken clay containers, called al-Haraban pottery and dating back to 3000 BC in the Indus Valley (Fig. 23), were found in Ras al-Jinzz, Sultanate of Oman. They represent the oldest evidence of trade from the last period of the Harappan civilization in India. Shipwrecks found off the coast of India indicate trade with Mesopotamia and Rome [402].

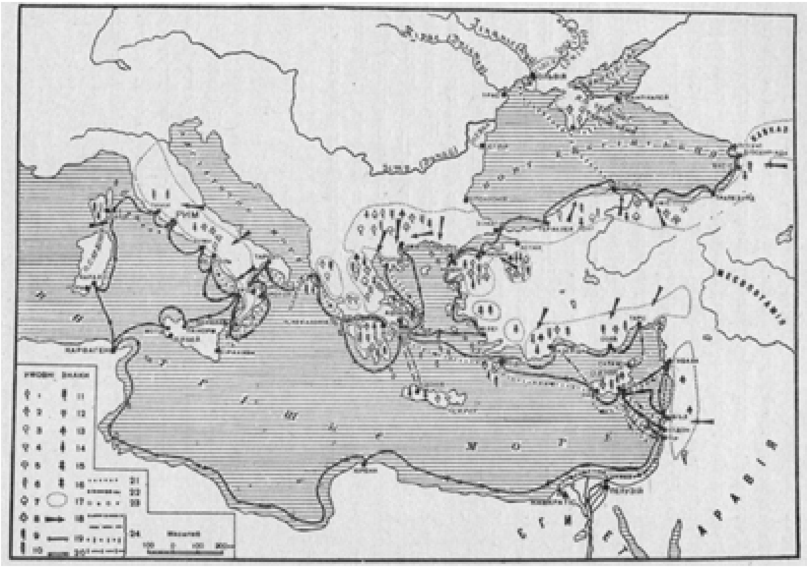
Wooden ships were commonly used for transportation. The materials for construction were imported from distant locations. For example, ancient Egypt sourced from Lebanon, Northern Iraq and Turkey, while the Greeks, Persians, and Romans obtained materials through tribute payments in the conquered and dependent lands, such as today's Bulgaria and Romania [138].

These cultures, including Sumerian [820], Egyptian [806], Hellenistic, and Roman, used clay for the production of transport and storage packaging due to the scarcity of wood caused by centuries-old deforestation for building homes and fuel, as well as 300 years of drought starting in the twelfth century BC [167] (shown in Fig. 24).

This was due to the available production technology, including tools and materials for manufacturing. Wood was expensive, while the clay was easily accessible. During this time, the first tools made of copper and its alloys, such as bronze, were utilized (Fig. 25). Evidence of bronze production was found before 800 BC in the Lake Balaton area of Hungary (Fig. 26). However, the primary tools used were stone tools, including those made of flint, such as striped flint (Fig. 27). For instance, the striped flint mine is present in Krzemionki (Opatowskie), Poland (see Fig. 28). Records indicate that mining activities have been ongoing there from the Neolithic and Bronze Ages, that is, from 3900-1600 BC. The striped flint extracted from Krzemionki was discovered 660 km away from the mine, as mentioned in reference [198]. The Krzemionki Opatowskie mine was added to the UNESCO World Heritage List on 6 July 2019 [203], [804].

22. Amphora with the decorative ornament of the Banpo culture in China, 4800 BC [512]

23. Fragment of al-Haraban pottery with a floral motif, found in Oman [811]



24. Occurrence of tree species and timber trade routes in the Hellenistic and Roman periods; 1-ash, 2-oak, 3-beech, 4-sycamore, 5-elm, 6- boxwood, 7-walnut, 8-maple, 9-spruce, 10-pine, 11-fir, 12-yew, 13-cedar, 14-cypress, 15-pine, 16-larch, 17-forested areas, 18-exporting areas, 19-route to Carthage, 20-route to Athens, 21-route to Corinth, 22-route to Egypt, 23-route to Rome, 24-presumed export routes [225]

25. View of the furnace for the production of bronze in ancient Egypt from the period of the XII Dynasty [249]

26. Diorama showing a model of a bronze smelting furnace from 800 BC in the Balatoni Múzeum, Keszthely, Hungary

27. View of the native Cretaceous striped flint nest in Krzemionki (Opatowskie), Poland

28. Reconstruction of the method of excavation of striped flint nests from about 1600 BC in the Archaeological Museum in Krzemionki (Opatowskie), Poland.

The term ‘amphora’ originated in Greek and Latin languages. It refers to a narrow vessel with handles on each side, also known as a vice. Amphorae with a so-called ‘foot’ were employed for storage, while those with pointed ends were utilized for transportation purposes. The earliest vessels of this kind have been discovered in northern Lebanon and northern Syria. These vessels date back to the 2nd millennium BC. The Canaanite pitchers were the most popular storage and transport vessels in Palestine during that period (refer to Fig. 29). These pitchers were also present in Egypt, Crete, and Thera [813][505], as well as in Mycenae and Athens.

Herodotus recorded that wine in clay vessels was imported from Hellas and Phoenicia to ancient Egypt. Egypt never ran out of empty vessels since each head of the county city was responsible for collecting and returning them to Memphis as per the regulations. Once filled with water, the vessels were transported to the Syrian Desert, presumably to the Sinai Peninsula [138].

In Greece, many types of amphorae were created starting from the seventh century BC (Fig. 30). The Greek islands, including Knidos, Kos, Chios, and Rhodes, developed unique types of these vessels. The amphorae were small enough for one person to carry and could be transported both by sea and land. Studies conducted on a sample of approximately 200 transport amphorae from the island of Rhodes indicate a stabilization of their capacity of 26.2 liters between 300 and 200 BC. The transport amphorae were unadorned but had stamps identifying their manufacturer [437].

29. Canaanite transport amphora found off the coast of the eastern Mediterranean coast from the fourteenth century BC [505]

30. Ancient Greek amphora from Crete, c. VIII-VII centuries BC [276]

All amphorae, regardless of their contents, needed to be sealed. The weight of transported goods and various ways of transporting and laying the amphorae required durable stoppers. Initially, utility amphorae were likely produced in the same workshops as painted ceramics, pithos, and terracotta. Each major commercial center had its own form of amphora, distinct from the vessels produced in other centers. Local clay with distinct features such as color and admixtures was used to craft the dishes. This enables precise identification of the origin of the vessels. Rhodes-made amphorae were the most popular among the various types available in Greece, possibly due to their superior quality. Meticulously crafted from pure, well-kneaded, clean, and unadulterated clay. Rhodian amphorae had a capacity of around 26 liters and stood approximately 80 cm tall. An empty amphora weighed around 30 kg. The shape of Rhodian amphorae was popular, a fact demonstrated by the use of the same shape for amphorae produced in Roman times [182]. Rhodes was one of the major producers of ceramic packaging in the ancient world. Archaeologists have found Rhodian stamps on amphorae, which prove that the quantity of amphorae produced at that time far exceeded the demand of local receivers. Despite their high price, amphorae were exported because of their quality and found many recipients.

Starting from the mid-fourth century BC, it became a common practice to mark specific groups of amphorae using a stamp. The stamp, usually located on the upper part of the container but occasionally found on the neck and the foot of the amphora, acted as a seal (see Fig. 31 and 32). The stamps were impressed on the amphora's soft clay even before it was fired. The stamps provide direct information about the time and location of the amphora's production. Aside from the primary stamps, additional stamps labeled as supplementary were affixed to the upper part of the container (see Fig. 33). Mediterranean centers such as Rhodes, Cnidos, Tazos, and Paros, as well as the centers of their production on the Black Sea, i.e. Sinope, Pontic Heraclea, and Tauride Chersonesus [73], stamped their amphorae. Since the 1930s, stamps on amphorae have been interpreted as evidence confirming trade contacts of the centers of the ancient world. Initially, the economic activity centers exporting their goods in ceramic packaging were measured by the number of stamped fragments of amphorae found at the studied archaeological sites. In Rhodes, until the end of the first half of the third century BC, one in every five amphorae had a stamp, while from the beginning of the second half of the third at the beginning of the first century BC, each amphora was stamped. Stamped amphorae were widely used in the ancient world, which suggests that they were mainly produced for export. This is supported by the fact that the regions known for their economic and commercial activity were also the main centers of production [182]. For Rhodes, the data shows that an official name stamp guaranteed the vessel's capacity. In the wine trade, the number of goods sold and purchased is crucial. Confirming the capacity of the amphora with a stamp improved transactions significantly. Export amphorae approved with a stamp greatly facilitated the operation of the tax collector. Rhodian income [73] heavily relied on the port tax.

31. Stamp of a Rhodian amphora with the name of its producer Hippocrates and an emblem – a rose; II century BC [73]

32. Stamp of the Sinopian amphora with the name of the producer Hephaistos and the astinom Demetrios III and the emblem – a woman's head in a crown; first half of the third century BC [73]

33. Additional stamp of the amphora produced by Hippocrates; II century BC [73]

In ancient times, the quality of a product was highly valued, and so was the packaging. Occasionally, the shape of the amphorae was altered. Nevertheless, this minor cosmetic change had little impact on the generally accepted shape and capacity of the amphorae [182]. The remains of a blast furnace for firing amphorae, which is now known as Amrija (Kom el-Idris), were discovered in Marea, Egypt. Amphorae production took place on a large scale, as demonstrated by the 8-meter-wide grate used for firing ceramics. The amphorae produced in this area were mainly used for transporting local products like dates and wine [744], as well as goods from the depths of Egypt that were shipped through the Nile branch, thereby contributing to the development of deep-sea trade [196].

Amphorae were a commonly used type of packaging for transportation. Past research has demonstrated that various products were transported in amphorae. These included both liquid and solid products such as water, wine, olive oil, honey, wax, oils, fruits (such as dates), cereals, spices [182], fish (brines and canned food), garum (a seasoning used in dishes, often by the Romans, made from fermented fish [32]), tar, and dyes [182]. In a study conducted by Brendan Foley of the Woods Hole Oceanographic Institution and Marie Hansson of Lund University in Sweden in 2011, it was discovered that amphorae were commonly used for transporting a variety of goods. DNA tests on five vessels confirmed the presence of grape remnants. Six amphorae [101] were found to contain traces of various substances that were commonly used in ancient Greece to preserve wine, such as mint, thyme, oregano, ginger, legumes, juniper berries, and pine resin.

Thanks to many years of research, the German Heinrich Dressel 1899 established a detailed chronology of individual types of amphorae from 129 BC to the third century AD (Fig. 34).

Greek colonizers founded Massalia (modern-day Marseille, France) around 600 BC. Trade began between settlers and local Celtic tribes, with one important item being amphorae filled with wine [515]. The wine grew rapidly in popularity among tribes in Western Europe. During the Punic Wars with Carthage between 264 and 146 BC, the Romans were affected by the strength of wine. Following the defeat of Hannibal and the victories in battles against the Macedonians and Syrians, Rome emerged as a secure and prosperous empire, undisputedly dominating the Mediterranean. The expansion of viticulture in Dalmatia, on the Iberian Peninsula, and in the British Isles was facilitated by the growth of the Roman Empire. The *Lex Claudia* de senatorial established by *Kuitus Claudius* in 218 BCE prevented senators from being involved in trade. Ownership of ships with a capacity of more than 300 amphorae, equivalent to 8,000 liters (26 liters per amphora) [224], was prohibited.