**ORIGINAL ARTICLE**

Emerging Trends in Manufacturing

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**ABSTRACT**

The manufacturing has been an important activity through the ages. The ancient manufacturing methods were casting, forging, welding, heat treatment, powder metallurgy and grinding etc. The manufacturing industry got mechanised after the invention of the steam engine in 18th century. Several machine tools such as the lathe, milling, boring, planer, shaper, grinder, power hack-saw etc. were developed to give faster production rate. With the passage of time, industrial automation paid a major role in development of the industry. Hard automation in the form of automatic turrets and special purpose machines contributed a lot towards mass production. Soft automation in the form of numerical control helped reduce batch size for precise manufacturing accommodating frequent design changes economically. Development of non-conventional manufacturing processes, and advanced measurement and instrumentation approaches contributed towards further advancement in manufacturing industry. Modern manufacturing world seems to be looking at the manufacturing system from a different perspective. A number of tools and techniques have been evolved to make the manufacturing industry competitive. This article presents a brief account of the development and recent trends in the manufacturing industry.

**KEYWORDS** manufacturing, machines, manufacturing processes, manufacturing systems

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**INTRODUCTION**

The life of early man was very tough. People used to live in caves and resorted to collecting fruits and hunting animals for food. They used to cover their body with leaves and skin of animals to protect from adverse weather conditions. They even did not have knowledge of fire. Metals were also not known.

With the development of civilisation, man learnt many things to lead life comfortably. In the stone-age, the manufacturing was an important activity, primarily used for sharpening of tools made of stone for snatching fruits from trees and hunting animals. In the metal age, man also learnt a few metallurgical processes. Manufacture of metallic tools for ploughing, hunting, fabrication of wooden items (such as furniture, boats, bullock-carts, chariots, etc.) have been of major concern. This led to the development of basic machine elements – the wheel & axle, the wedge, and the lever, etc. Further developments include manufacturing of the sophisticated sharp and pointed weapons used in wars, and the ornaments and jewellery.

The ancient manufacturing methods were wood working, casting, forging, welding, heat treatment, powder metallurgy and grinding, etc. The methods were highly dependent on the skill and experience of artisans. In general, the manufacturing was job-order based, and the production rate was very poor. In the absence of the concept of spare parts, the repair and maintenance was a very difficult and irritating job even to a skilled artisan. The civil engineering and the mechanical engineering were the two major engineering disciplines known, and growth of both the disciplines remained mutually supportive.

With the passage of time there has been continuous development in different walks of life. The first major development in mechanical engineering took place in 18th century with the development of steam engine. The use of engine power facilitated industrial mechanization and revolutionised the manufacturing world. The second major headway was made in 19th century with the invention of useful application of electricity, giving rise to another important engineering discipline – the electrical engineering. This permitted installation of independent electric motor with each machine tool. Growth of all the engineering disciplines is interconnected and therefore the manufacturing world got benefitted from the development taking place in other disciplines. The third major development occurred in the 20th century with the invention of mini-computers, microprocessors and artificial intelligence techniques, which facilitated improvement in control system of machine tools. This led to the development of numerical control and sophisticated data storage devices, and thus made possible the evolution of CAD/CAM based manufacturing technology.

Modern manufacturing system is very complex. Apart from improvement in the existing manufacturing processes and development of the new ones, efforts are being made to make the manufacturing practice competitive and economically viable, by proper design and analysis of the overall system, and making optimal use of resources. This article presents a brief discussion of the development of the manufacturing system over the millennia.

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Rest of the article is arranged as follows. The following section presents a brief discussion of development in pre-industrial age, followed by the development in the industrial age in the third section. The fourth section presents advanced manufacturing practices adopted in the 20th century. The fifth section deals with the modern manufacturing system. The last section summarises the whole presentation and outlines the recent trend in manufacturing.

DEVELOPMENT OF MANUFACTURING IN PRE-INDUSTRIAL AGE

With the development of civilisation, man learnt about metals. The Copper Age (7700 BC to 2800 BC) was followed by the Bronze Age (2800 BC to 1200 BC) and the Iron Age (1200 BC onwards) in order. The ancient manufacturing methods were wood working, heat treatment of metals, sheet metal forming, casting, forging, welding, powder metallurgy and grinding, etc. The manufacturing practice was based on application of hand tools or manually operated machines such as knife, saw, chisel, hammer etc. A few machines based on simple mechanisms, such as, the tree lathe (also called rope lathe) for wood turning, and the bow drill, for drilling holes were also evolved. Functioning of these machines was based on reciprocating rotation of work piece or the cutting tool. The manufacturing methods were very simple, and highly dependent on the skill and experience of artisan. In general, the manufacturing was time consuming and job-order based. In absence of the concept of spare parts, the repair and maintenance was a very difficult and irritating job even to a skilled artisan.

In due course, efforts were made to improve the quality of hand tools, and the mechanisms of existing machines for a better and convenient functioning so as to achieve higher production rate. With the invention of other sources of power, such as, water wheels and windmills, etc. to supplement the manual power, the man learnt conversion of the rotary motion into reciprocating motion and vice-versa. In the Medieval Age, the mechanisms of the existing machines underwent further improvement, and a few new machines were evolved, so as to make use of advanced power sources. The improved machinery was more convenient in operation and capable of meeting more force and power requirements, coupled with the higher production rate. This gave rise to development of continuous-rotation lathe around 1560s, and the rolling mills around 1590. The improved lathe permitted metal machining in addition to the wood turning; and the rolling mill permitted the bulk metal-deformation practice so as to produce uniform cross sectioned objects and rolled plates and sheets. The existing manufacturing methods and the machinery kept on improving, and the new ones evolved over the centuries. The development of manufacturing in the pre-industrial age has been depicted in Table 1.

DEVELOPMENT OF MANUFACTURING IN INDUSTRIAL AGE

There have been continuous efforts to develop effective sources of power to replace the manual or the animal power in different activities of life. With the result windmills and water wheels were developed and were used in industry to reduce manual labour. However, effectively the first Industrial Age is considered to have begun with the invention of the steam engine in the 18th century. Further major improvement has been observed with the invention of electricity, and its useful applications, towards the end of the 19th century. This has been considered as the second industrial revolution. Development of manufacturing in the Industrial Age has briefly been described in this section, and has been depicted in Table 2.

Table 1: Pre-industrial age.

<table>
<thead>
<tr>
<th>Metallurgical processes</th>
<th>Metal forming</th>
<th>Material removal processes</th>
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<tbody>
<tr>
<td>Extraction of metals from ores</td>
<td>Forging</td>
<td>Wood working – sawing, turning, drilling, etc.</td>
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<tr>
<td>Casting low melting metals</td>
<td>Development of rolling mills around 1590</td>
<td>Application simple machines based on reciprocating rotation of tool or work piece, such as, tree (rope) lathe for turning, and bow drill for drilling</td>
</tr>
<tr>
<td>Powder metallurgy of high melting metals</td>
<td>Sheet metal forming</td>
<td>Grinding</td>
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<tr>
<td>Forge welding of metals</td>
<td></td>
<td>Metal machining (in middle ages) using continuous rotation lathe around 1560s</td>
</tr>
</tbody>
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### Table 2: Industrial age.

<table>
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<tbody>
<tr>
<td>Steam engine as the source of mechanical power</td>
<td>Electricity as (i) source of mechanical power, (ii) source of heat, (iii) source of light</td>
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</tbody>
</table>

**Industrial Age (1650–1950)**

**Machine tool technology**
- New era in metal machining:
  - Development of rigid machines, such as, engine lathe, boring machine (1775), screw machines, mechanized hacksaw, etc
  - Crank press (1850) for press working operations

**Foundry work and metallurgical processes**
- Foundry flask for sand and loam molding (1709)
- Malleable iron, known today as "European Whiteheart." (1720)
- Application of cupola (1794)
- Centrifugal casting (1809)

**Bulk metal forming**
- Extrusion, for production of uniform cross-sectioned components (1790s)

**Machine tool technology**
- Development of electric motor, and installation of independent electric motor to machine tools
- Development of new machine tools - milling machine, broaching machine, drill press, planer, shaper, grinder, etc. This led to the development of the heat resistant carbide tool materials using powder metallurgy (1930s)
- Application of rigid automation implemented using cam-follower mechanisms leading to development of special purpose machines (SPM), copying milling, copying lathes, single & multi-spindle automat
- Mass production – limits, fits, tolerances and interchangeability, development of jigs & fixtures, dies, etc.
- Jig boring, jig grinding, gear manufacturing machines
- Precise tool room machines, such as, different types of grinders, copying and die sinking machines etc.

**Foundry work and metallurgical processes**
- Development of open hearth furnace (1845), the electric arc furnace (1906), high-frequency coreless electric induction furnace (1930), etc.
- Bessemer converter (1851), to convert pig iron into steel.
- Metallographic inspection techniques (1863)
- Sandblasting (1870)
- Sly tumbling mill (1880s)
- Rediscovery of investment casting (1897)
- Renaissance of powder metallurgy for production of tungsten filament for light bulb (1900s)
- 18/8 stainless steel (18% chromium, 8% nickel (1924)
- Ductile iron (cast iron with fully spheroidal graphite structure, 1948)

**Joining of metals**
- Carbon-electrode arc welding, electric resistance welding, thermite welding, and oxy-acetylene welding (1880–1900)
- Hydrogen welding, submerged arc welding, TIG welding, MIG welding, and electroslag welding etc. (1924–1950)

**Bulk metal forming**
- Thread rolling
Application of Engine Power: First Industrial Revolution

A lot of development has been observed in the manufacturing practices over the millennia. The invention of the steam engine in the 18th century brought about the first major industrial revolution throughout the world. The use of manual power was replaced by the engine power. The mechanised power generated by steam engine was transmitted to the machines via line shafting, allowing faster and easier production. Several new manufacturing processes were evolved and the existing ones were improved. After centuries of efforts several machine tools such as the engine lathe, boring machine, screw machines etc. were developed to give faster production rate. The engine lathe evolved into heavier machine with thicker and more rigid parts, driven by engine power became popular for metal machining. Because of its diversified functional capability, it is considered to be the most important machine, and the queen of machine shop. On the similar principle, the boring machine was developed in 1775 for machining precise bore in metals. The screw machine was developed for faster and automatic production of small components such as, nails, screws, nuts, bolts etc. As the demand to cut and saw metals grew, the mechanised hacksaw was also developed and created to alleviate manual effort. The extrusion was added to the bulk deformation processes for production of uniform cross-sectioned components in 1790s.

Application of Electricity: Second Industrial Revolution

The machine tools observed further significant improvements with the development of useful applications of electricity in late 19th century. The engine power was replaced by the electric power. The invention of electricity led to the renaissance of powder metallurgy for production of tungsten filament for light bulb (1900s).

Machine tools, metal machining and metal forming

The development of electric motor appeared to be boon to the machine tool industry. This permitted installation of independent electric motor to machine tools. In addition to improvement in the existing machine tools, several new machine tools such as, milling machine, broaching machine, drill press, planer, shaper, grinder etc. came into existence. The development in machine tools needed better quality of cutting tools to be operated at higher cutting speeds. This led to the development of the heat resistant carbide tool materials using powder metallurgy (1930s).

The quest for efficient and precise mass production led to the use of automation. Rigid automation implemented using cam-follower mechanisms made possible automatic tool (or work-piece) advance, machining, tool retraction, tool change and work piece retraction, etc. A variety of machine tools such as, special purpose machines (SPM), copying milling, copying lathes, single & multi-spindle automatic turrets were evolved. These machine tools are highly specialised ones, and are useful for only a particular operation on a given job. Because of this they are applicable only for mass production. It is difficult to make changes in machine-hardware to accommodate design changes in the work-piece.

The mass production is based on manufacture of identical components in a large quantity. Although this concept existed earlier, the same was popularised in 1910s by Henry Ford’s Ford Motor Company. This led to the development of a new concept of limits, fits and tolerances to ensure interchangeability of components. To realise easier, faster and economical production, jigs & fixtures, and dies for press working, forging and casting were developed. Precise tool room machines, such as different types of grinders, copying and die sinking machines, jig boring and jig grinding machines were developed for manufacture of these tooling. Other developments include evolution of gear manufacturing (hobbing/shaping/shaving) machines, thread rolling machines, and multiple-spindle drilling heads etc.

Foundry practice

The foundry practice also made a sea change in technology. Various furnaces, such as the open hearth furnace (1845), the electric arc furnace (1906), high-frequency coreless electric induction furnace (1930), etc. were invented. The Bessemer converter invented in 1951 makes use of blast of air to burn out the impurities, silicon, manganese and excess carbon in pig iron, so as to convert it into steel. New materials, such as the 18/8 stainless steel (18% chromium, 8% nickel, 1924), and the ductile iron (a cast iron with fully spheroidal graphite structure, 1948) were invented.

Metallographic inspection techniques were introduced in 1863 to physically examine the casting surfaces for quality analysis. The Sandblasting was introduced in 1870 to clean large castings. The Syl tumbling mill was introduced in 1880s as the first cleaning machine for small castings. The once forgotten investment casting process was rediscovered 1897. This process seems to have been in practice in ancient times around 3000 BC in Harappa & Mohanjodaro and remained popular for millennia in different parts of the world for production of complicated shapes.

Welding processes

The invention of electricity started a new era in welding used for joining of metals. Several welding processes, such as, carbon-electrode arc welding, electric resistance welding, thermit welding, and oxy-acetylene welding were evolved (1880–1900). Further developments include atomic hydrogen welding, submerged arc welding, TIG welding, MIG welding and Electroslag welding.
(1924–1950). Improvement in the technology further enhanced manufacturing activity and strengthened the concept of mass production.

**ADVANCED MANUFACTURING PRACTICE**

Need is the mother of all inventions. In 1940s during the World War II a new era started in manufacturing with a major change in the existing system to meet the demand of production of sophisticated weapons in huge quantities. The cutting tools were further improved to fulfill the need of much higher production rate. Research for the development of new manufacturing methods was also initiated to (i) obtain flexible automation to handle frequent design changes in the work-piece just by changing machine-software, and (ii) machine hard-to-machine materials, such as hardened steel, tungsten, titanium etc. The former with the invention of minicomputer and microprocessors, led to the development of numerical control (NC) of machine tools, where the relative motion between the work-piece and the tool is controlled by direct insertion of numbers, symbols and alphanumeric characters etc. The machine tools based on this principle are known as NC machine tools. In addition to the numerical control of machine tools, the robot technology and rapid prototyping technology are also significant developments. These approaches have been quite helpful to manufacturing practice with special mention to safety, precision and production rate. The latter resulted in the development of non-conventional machining processes, most of which are based on different principles of chip-less machining concepts. The development of new manufacturing methods and machine tools once again revolutionised the manufacturing industry throughout the globe. Details of the advanced manufacturing practices have been depicted in Table 3.

A number of useful textbooks are available on these advanced manufacturing methods. Research is still going on to improve the existing manufacturing processes for improving their capability, better precision, reduction in power consumption, and higher production rate.

**Numerical Control of Machine Tools**

NC machine tools are useful for consistently providing very high precision in manufacturing. Here the human element is involved just for preparation of part programmes (by a skilled part programmer) as per predetermined tool path. The machine controls i.e. the relative motion between the work-piece and the cutting Table 3: Advanced manufacturing practice.

<table>
<thead>
<tr>
<th>Development of Microprocessors, minicomputers, advanced control system, etc.</th>
<th>Development of non-conventional machining operations</th>
<th>Miscellaneous developments in core manufacturing processes</th>
</tr>
</thead>
</table>
| **NC Technology, i.e. Numerical Control of Machine Tools (1952)**  
**Robotics (1961)**  
**Rapid Prototyping or 3-D Printing Technology (1988)**  
Material removal processes and machine tools for  
- Material removal from hard-to-machine materials – metals, ceramics, composites, etc.  
- Producing complex shapes  
The processes developed include:  
- Abrasive Jet Machining (AJM),  
- Abrasive Flow Machining (AFM),  
- Electro-discharge Machining (EDM), and (wire cut EDM),  
- Chemical Machining (CHM), Electro-chemical Machining (ECM),  
- Electro-chemical Grinding (ECG),  
- Photo-chemical Machining (PCM),  
- Ultra-sonic Machining (USM), Laser Beam Machining (LBM), Electron Beam Machining (EBM), etc.  
- Shell mould casting (C-process, 1944–1947)  
- Casting of metal-matrix-composites (MMC, 1965)  
- Scanning electron microscope (SEM, 1965)  
- New applications of the powder metallurgy for better quality automobile components (1960s) and aircraft engine turbine components (1980s)  
- Advanced welding processes – ultra-sonic welding (USW), laser beam welding (LBW), electron beam welding (EBW), friction welding (FRW), etc. |
tool, loading/unloading of the work-piece, tool change and coolant application, etc., are accomplished with the help of a punched tape or a punched card, prepared in accordance with the part programme. The punched tape and the punched card constitute the machine-software. Frequent design changes in the work-piece can easily be accommodated just by feeding the machine software appropriately. Online data editing facility enables the operator to make necessary changes during the actual machining operation. Flexibility of these machine tools to carry out various manufacturing operations in a single set-up significantly improved the productivity. Because of this feature the NC machine tools initially meant for turning and milling operations are more commonly referred to as the NC turning centre or NC machining centre respectively.

Development of the NC machine tools has been a boon to the manufacturing world. The NC technology underwent further improvement to make it more convenient. The application of the punched tape/card was eliminated, and direct feeding of the part programme to the machine tool was introduced. This technology is known as the computerised numerical control of machine tools (CNC). Subsequent developments of this technology include the direct numerical control (DNC), adaptive numerical control (ANC) and StepNC, etc. A large number of sophisticated machine controls have been evolved for the machine tools based on this technology. Also, a few software packages for automatic part programme generation, such as MasterCAM, EdgeCAM, etc. have been developed.

The NC technology now-a-days is not limited to only the material removal processes, rather, it has been extended to other manufacturing processes such as metal forming, welding, etc. The research is still going on to improve the capability of the technology, to meet the requirements of the real-world manufacturing problems.

Non-conventional Machining Methods

The development of non-conventional manufacturing methods mainly takes care of machining of the hard-to-machine materials. This made possible the use of better quality tool and die materials, which ultimately resulted in increased productivity on account of an increase in tool and die life. These manufacturing methods are also useful for producing certain shapes difficult to produce conventionally, e.g. square and blunt holes and other complex shapes.

The manufacturing methods and the machine tools developed in this category are, abrasive jet machining (AJM), abrasive flow machining (AFM), electro-discharge machining (EDM), wire cut electro-discharge machining (wire cut EDM), chemical machining (CHM), electro-chemical machining (ECM), electro-chemical grinding (ECG), photo-chemical machining (PCM), ultra-sonic machining (USM), laser beam machining (LBM), electron beam machining (EBM) etc. Research is continuously going on to improve the performance of these processes and development of the new ones.

Miscellaneous Advancements

Apart from these machining methods, a few joining processes, such as, ultra-sonic welding (USW), electron beam welding (EBW), and laser beam welding (LBW), friction stir welding (FSW), etc. have also been developed to meet precision requirements in welding of sophisticated components without distortion.

The shell mould casting (Croning Process) also appears to be a significant development in foundry practice. The process can easily be automated and thus can be considered to be quite useful for mass production. The scanning electron microscope was developed for inspection and testing of metals (1965). New applications of the powder metallurgy were explored for production of better quality automobile components (1960s) and aircraft engine turbine components (1980s).

MODERN MANUFACTURING SYSTEM

Towards the end of the 20th century, the world economy observed a major change. Globalisation and liberalisation of economy created a highly competitive environment in the manufacturing industry. The changed environment is characterised by (i) reduction in batch size, (ii) frequent design changes and (iii) increased focus on quality, changing the earlier concept of ‘quality control’ to ‘quality assurance’, and ‘satisfied customer’ to ‘delighted customer’ etc. This gave rise to the modern manufacturing system, which does not mean only the shop floor manufacturing activity; rather it encompasses all the interrelated functions including production planning, process planning, shop floor manufacturing and material handling, assembly, inspection & testing, and after sale service for the repair and maintenance etc.

With the new approach, the earlier concept of flexible manufacturing system (FMS), where the focus is on the flexibility of the machine tools on the shop for processing of different kinds of work pieces, is no more significant. To meet the requirements of changed environment researchers have introduced several new concepts, as detailed below. The modern manufacturing system has been represented in Fig. 1.

- Total Quality Management (TQM): The TQM stands for complete quality management at every step and in all relevant functions of the product life cycle so as to produce acceptable quality product without any rejection.
- Manufacturing Resource Planning (MRP-II): The MRP-II stands for planning of all the resources such as, raw
Emerging trends in manufacturing

The manufacturing has been an important activity through the ages. The traditional manufacturing methods were wood working, casting, forging, forge welding, powder metallurgy, heat treatment, grinding and turning etc. The manufacturing practice went on improving through centuries but the progress remained very slow.

The manufacturing industry got mechanised after the invention of the steam engine in 18th century. Several machine tools such as the lathe, grinders were improved, and others such as milling, drilling, boring, planer, shaper, power hack-saw etc. were developed to give faster production rate. Later on, during the development, useful applications of electricity in 19th century facilitated the use of independent electric motors for driving the machine tool spindles, and thus contributed towards further development of machine tools. With the passage of time, industrial automation paid a major role in development of the industry. Hard automation in the form of automatic turrets and special purpose machines contributed a lot towards in mass production. With the invention of minicomputers and microprocessors in the 20th century, the soft automation in the form of numerical control helped reduce batch size for precise manufacturing, and thus facilitated economical and frequent design changes. Development of powder metallurgy, non-conventional manufacturing processes, rapid prototyping, advanced welding techniques and measurement and instrumentation approaches contributed towards further advancement in manufacturing industry. These advanced manufacturing techniques present a lot of research opportunities in this area.

In modern industrial world, the manufacturing system presents a very complex picture. Apart from improvement in the existing manufacturing processes and development of the new ones, efforts are being made to make the manufacturing practice competitive and economically viable, by proper design and analysis of the overall system, and making optimal use of resources.

A number of concepts such as Manufacturing Resource Planning (MRP-II), Lean Manufacturing System (LMS), Agile Manufacturing System (AMS), Intelligent Manufacturing System (IMS), Holonic Manufacturing System (HMS), Re-configurable Manufacturing System (RMS), Total Quality Management (TQM), etc. have evolved. Several software tools have been developed to simulate the real world manufacturing system for proper analysis. Development and application of the software tools for design and analysis of manufacturing system offers numerous research opportunities in this area.

The modern manufacturing system is very complex, the research on application of the concepts is still in infancy stage, and a lot is yet to be done to achieve the goal. Efforts are being made all over the world both in academia and industry to work in this direction.

SUMMARY

The manufacturing has been an important activity through the ages. The traditional manufacturing methods were wood working, casting, forging, forge welding, powder metallurgy, heat treatment, grinding and turning etc. The manufacturing practice went on improving through centuries but the progress remained very slow.

The manufacturing industry got mechanised after the invention of the steam engine in 18th century. Several machine tools such as the lathe, grinders were improved, and others such as milling, drilling, boring, planer, shaper, power hack-saw etc. were developed to give faster production rate. Later on, during the development, useful applications of electricity in 19th century facilitated the use of independent electric motors for driving the machine tool spindles, and thus contributed towards further development of machine tools. With the passage of time, industrial automation paid a major role in development of the industry. Hard automation in the form of automatic turrets and special purpose machines contributed a lot towards in mass production. With the invention of minicomputers and microprocessors in the 20th century, the soft automation in the form of numerical control helped reduce batch size for precise manufacturing, and thus facilitated economical and frequent design changes. Development of powder metallurgy, non-conventional manufacturing processes, rapid prototyping, advanced welding techniques and measurement and instrumentation approaches contributed towards further advancement in manufacturing industry. These advanced manufacturing techniques present a lot of research opportunities in this area.

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Figs. 1 Modern manufacturing.

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