Component Based Modular Elevator

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Abstract. This paper addresses a "Component-based Modular Elevator" (CBME) design. The idea is to have readily available components (mechanical, electrical & electronic) of an elevator ideally in a local warehouse, that are totally modular in nature, easily configurable to build one entire elevator system. This method facilitates easy procurement, deployment, and installation of the elevator without a need of placing an order with the manufacturing plants (OEM)/ logistics centers.

The elevator industry supply chain includes all the processes involved in ordering, producing, shipping, and other logistics delivering to the construction sites. The local selling companies do not have manufacturing plants but import the materials from their principal factories' world over (mainly from China & Europe).

Modular design is a method of breaking down a system into smaller sections/modules that can be constructed individually and then combined to form a larger system. From less customization and design flexibility, modularity also has advantages, such as augmentation (modernization). The design aims to combine the benefits of standardization (low manufacturing costs) and customization.

Traditionally built elevators still need to be manufactured as per specifications, even if they are standard models. Whereas, from a segmented modular elevator design, different models of elevators could be built up using segments that can add up to have different capacity elevators using prefabricated elevator modular mechanical & electrical components. The concept of modular elevator design was always present, but not at the component level. The advantage we can gain from such a design is that the parts can be pre-ordered (or 3D printed), stocked, and these can be assembled at the job site to suit the specification.

A methodology proposing CBME essentially takes a specific modular design of major components of an elevator application as an example to show the development of a fully modular elevator.

1 INTRODUCTION

The vertical transportation industry is usually categorized by product (new passenger/freight lifts, escalators, moving walkways), service (installation, modernization, and repair) and market (residential, commercial & industrial). A good vertical transportation system is one of the first aspects of a good building design. Over the past few centuries and particularly in recent decades there has been rapid **urbanization** and the world has witnessed a mass migration of populations from rural to urban areas. More than 4.3 billion people now live in urban areas as per estimates from the UN.

This means over half of the world (55%) live in urban settings. With the world population growing and with the lack of livable area, housing has increased into multi-level units, thus the need for vertical growth and transportation too has been increasing proportionately.

1.1 Growth And Future of World Lift Industry

The global lift and escalator market was valued at USD 79.70 billion in 2021. The market is projected to grow from USD 83.86 billion in 2022 to USD 132.08 billion by 2029, exhibiting a CAGR of 6.7% during the forecast period. The global COVID-19 pandemic has been

unprecedented, with lower than anticipated demand across all countries compared to pre-pandemic levels. Based on the analysis, the global market had exhibited a decline of 3.5% in 2020 as compared to 2019.[1]

Post Covid, the rising investments in commercial and residential infrastructure projects in the developing and developed economies and resumption of construction activities on some of the major projects in several countries are expected to bring in positive results in elevator and escalator market growth. Also, the increasing focus of manufacturers in offering products with improved safety is expected to result in market growth.[1]

2 STRATEGY IN THE ELEVATOR INDUSTRY

The lift industry is currently in the maturity stage if we consider the typical electric traction & hydraulic elevators. However, traditional elevators still experience the growth stage as the companies have been coming up with new features and improvements on these regularly, like the machine room less (MRL) elevators, green technology in the last 2 decades and recently the revolutionary linear motor technology ropeless lifts , carbon fiber ropes, DC battery powered lifts, usage of IoT, smart elevators etc. Every few years, as technological improvements happen, the demand for these starts to rise and then matures as customers start waiting for newer models and better features.

2.1 Strategic Group Map for Elevator Industry

Firms in the same strategic group in the lift industry have two or more competitive characteristics in common, like sell in same price/quality range, be vertically integrated to same degree, have comparable product line breadth, use of identical technological approaches etc. [8]

Although, the groups do not expose big differences in how all the companies in a country /region perform, except for some “other smaller” companies that supply elevators to builders who are very cost conscious. Only Mitsubishi, Otis, Kone, TKE & Schindler compete neck and neck on large projects where brand name, quality, and price matters to the clients.

2.2 Elevator industry and Blue ocean thinking

- ‘Red Oceans’ in elevator industry are already well defined (mid to high rise market) and competition is very high.

- ‘Blue oceans’ are new market spaces where competition is minimized. The innovations in Hybrid or fully battery-operated elevators, LVA (low voltage architecture), and open loop control systems, super high-rise systems, and IoT are future innovations in elevator technology and major brands are working hard towards them. These market spaces are currently intensively explored by all major brands.

However, the concept of modular (ready in stock) lifts is yet to be explored in the elevator product range!

2.3 Elevator Industry’s Critical Success Factors

In the service industry, particularly the volatile, capital-intensive elevator industry, success factors cover a wide spectrum: people, service, product, innovations, revenue/cost control, materials, and financial management. Common types of key success factors of elevator industry:

2.3.1 Technology & innovation driven:

- Product innovation capability (like flat steel belt, battery driven elevator, Carbon fibre ropes and the recent TKE Multi® rope less lifts etc.)

- Expertise in a given technology (Green technologies for CO2 foot print reduction using VF & regenerative drive systems, compact gearless machines, no lubrication systems, LED lighting, lifts going under standby mode when not utilized etc.)

- Latest using IoT enabled elevators and use artificial intelligence (AI) to enable vertical transportation of passengers and commodities effectively. It is also a process of upgrading the lift in order to handle new technology, perform better, improve safety, and ensure the maintenance is up to date.

2.3.2 Manufacturing driven:

Although a major percentage of the elevators are imported into most of the countries from China, Far East, Europe, Japan, US, India etc., the manufacturing processes will have a direct or indirect impact of the cost & quality of the final products.

There are several factors affecting manufacturing costs: [9]

- Labour Costs – The socio-economic conditions in the area where the activity is done frequently affect labour expenses. Working with suppliers who employ lean manufacturing techniques translates to least amount of waste and greatest quality.

- Raw Materials – Raw materials are commodities that are traded extensively on the global market. With very few exceptions, the cost is determined by the amount of material consumed, so it doesn't really matter where production takes place.

- Part Complexity – Complexity doesn't always improve a product's look or performance. In fact, overly complex designs can hinder a product's utility and performance while being more expensive to make.

- Volume – Raw material suppliers occasionally provide discounts for large purchases; thus, volume is another factor to take into account. This should be taken into account for the course of the product, not just for one particular production run.

- Precision – Repeated accuracy is what is meant by precision which is easily achieved with modular products. It has to do with consistency within a range of allowable deviations from the nominal value. Many product developers are unaware that investing in ever-increasing precision and accuracy leads to cost reductions drastically.

- In country value - For the countries to remain economically sustainable long-term, it is key to ensure the development of its local talent, diversification of its GDP through sourcing more goods and services locally. It means engaging with local stakeholders to hire, buy and invest locally. To achieve this, many Middle East countries have either approached this by specific contractual terms or by an ICV program. Here, a criterion is set to calculate an ICV score for a supplier and that score is used in making procurement decisions.

- Environmental related measures -
  - CO2 emissions reduction
  - Green production cycle: Selecting all components for optimal performance with the smallest carbon footprint possible.
  - More recycling, less waste, innovative solar system power

2.3.3 Distribution driven

The 1970s to 90s saw many elevator companies being operated by agents and not directly by the foreign principals. But in the late 90s the trend changed, big elevator companies became major shareholding companies operating directly implementing their standard policies and procedures, although there are still many elevator company agents operating. However, the manufacturing facilities are still almost non-existent in most of the countries.

3 THE CHALLENGES IN THE ELEVATOR INDUSTRY

The following are the most common challenges most lift selling companies face:

- Forecast accuracy and unpredictable demand from clients. This is never constant and varies due to a combination of several issues like construction delays, client indecisiveness, delays in approvals etc.
- Client, Main contractor & Consultants general delays and elevator contractor award finalization delays (at times, this happens even during the last stages of construction).
- As a result, demand for the shorter delivery times shall always remain and elevator manufacturers have to gear up for this demand uncertainty at all times. The trend of shorter lead time significantly impacts the project's duration. Developers need to be vigil about the trends in the market and human behaviour.
- Supply chain issues: Supply Chain is a cohesive built-up process and like any other manufacturing supply chain [7]. It comprises of two combined processes such as Production Planning & Inventory Control and Logistics Process as shown below:

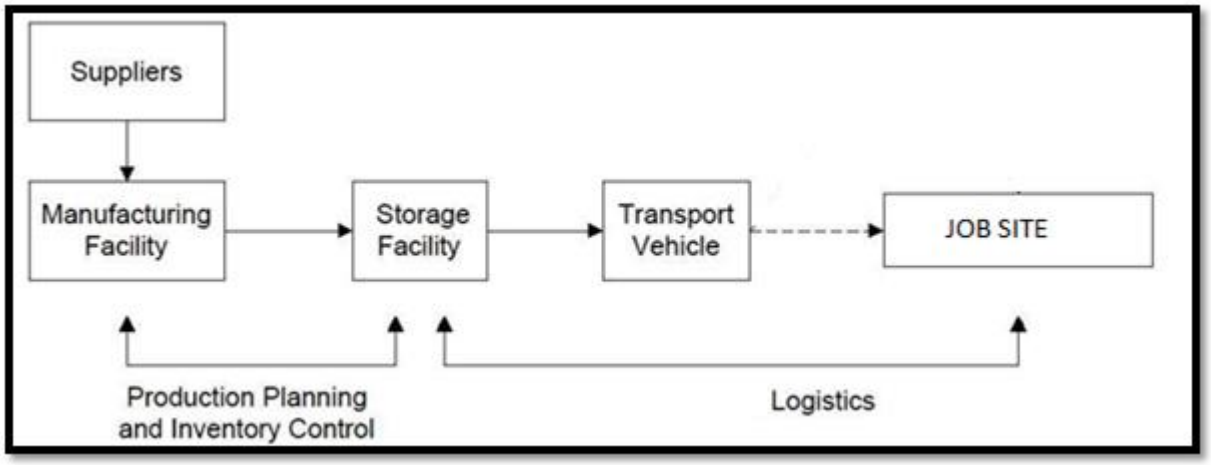

Table 1– Traditional Supply chain management in Elevator Industry

Lift selling companies in most countries do not own their manufacturing plants but import the materials from their principal factories world over. However, with most factories plagued with delayed manufacturing schedules, shipment, and other last mile logistical issues, these very often lead to overall delayed delivery times.

The manufactured goods are usually shipped through several sea ports. This brings a huge challenge to the elevator companies. Blockades at ports during peak seasons like in summer and like in the current pandemic situation in China has created backlogs of thousands of containers with a loss of millions of dollars to businesses.

- Unpredictable demand: This is independent of forecast accuracy issues; unpredictable demands are mainly resulting from project announcements delays and overall market scenarios in real estate/ construction business.

- As a result, the major lift companies tend to lose of lot of market share in the lower segment, where the "other smaller" competitors (and the trading agencies) provide quick deliveries to the clients in urgency. Some have stock of the major components, and they shop around for other parts, procure, assemble and handover to the client in a short time.

A ready in stock elevator or a modular elevator locally would be a perfect solution in such situation, thereby avoiding this entire process of ordering, shipment/logistics management! The current sustainability requirements from authorities demand local procurement as much as possible that necessitate the requirement of a CBME.

1. MODULAR LIFT & METHODOLOGY

As the global elevator industry continues to restructure and consolidate (post Covid), the home base of operations of the major players is becoming increasingly less relevant to the competitive dynamics of the business, with a handful of multinational companies dominating the business in most geographic areas – especially with respect to product manufacturing.

In this extremely challenging market, although the construction industry is moving slow-paced world over, the profit margins in the new equipment (installation) market are badly hit due to the extreme competition. For a strong foothold in the industry, major lift suppliers are continually investing in innovation & RD and aim to bring out new products every three to four years.

More than 60% of the new elevators sold and installed are between the lower end capacities i.e., 320kg to 1000kg that are mostly installed in private homes/villas, apartments & small offices. The idea of an innovative "Modular Segmented Elevator" was mainly within this range of duty loads that is readily available on stock and on a "one size fits all" basis.

Having a modular elevator product ready in stock can reduce this lead time, drastically reduce logistics, installation costs and increase their respective market share by offering ready-to-be-installed elevators by any supplier.

This product should be wholly modular in nature, segmented, ready in stock and available 24/7 with the local elevator selling companies, who do not possess elevator manufacturing facilities in their operating country. This reduces their total dependency of placing orders with the overseas manufactures (OEM/logistics centers) and avoids delays in ordering, manufacturing, shipping, and other usual processes involved. This ultimately might bring the order & manufacturing cycle time to zero (from the current global average 8 weeks manufacturing and 5 weeks shipment).

In the last decade, the concept of modularity has caught the attention of engineers, management researchers and corporate strategists in a number of industries. When a product or process is "modularized," the elements of its design are split up and assigned to modules according to a formal architecture or plan. [3]

A complex system can be easily managed by dividing it into smaller modules and examining each piece separately. Modularity refers to "the degree to which a system's components can be separated and recombined" into new configurations with little loss of functionality). [10]

Several powerful forces are behind modularization:

- the rate of technological change is accelerating,

- customers, empowered by advanced technologies, are demanding greater product variety at lower prices, and
- technology-intensive products are becoming more complex. The potential benefits of modularity include economies of scale, increased feasibility of product/components change, increased product variety and reduced lead time, decoupling tasks and ease of product upgrade, maintenance, repair, and disposal.

The concept of modularity is commanding increasing attention from researchers because of its capability to cope with a turbulent manufacturing environment. One of the key principles that will determine the factory of the future is the modular organization of manufacturing processes, which promises to combine the advantages of standardization and flexibility. [10]

So, a modular system can be characterized by the following:

- Functional partitioning into discrete scalable, reusable modules consisting of isolated, functional elements
- Rigorous use of well-defined modular interfaces
- Ease of change to achieve technology transparency

Besides reduction in cost (due to lesser customization), and flexibility in design, modularity offers other benefits such as augmentation (adding new solutions by merely plugging in a new module).

Modular design is an attempt to combine the advantages of standardization (high volume normally equals low manufacturing costs) with those of customization. A downside to modularity (and this depends on the extent of modularity) is that modular systems are not optimized for performance. This is usually due to the cost of putting up interfaces between modules

3.1 How can modular elevators be an alternative to stick-built elevators?

- *Shorter Lead Time*: A complete, customized elevator can be at the door ready to install in a week's time after drawings are approved. Typical elevators have a 4 to 5 months lead time.
- *Faster Installation*: Elevator installation is one of the most problematic, expensive, and time-consuming aspects of construction. Modular elevators can be stored, ready in stock or transported in a short time and are ready for installation. Installation can be done in the shortest possible time, minimizing disruption at the job site. Stick-built elevators generally take about 3-4 weeks to assemble on-site.
- *High Quality*: Standard elevator parts can be built under controlled factory conditions to meet strict quality and tolerance standards.
- *Lower Cost*: Pre-engineered elevators save time and money as standardization brings down the costs drastically. Unlike conventional elevators, modular elevators allow for more design freedom, increased functional versatility and an uncomplicated solution for buildings that need to adapt or modernize. They can also enable virtually any kind of facility to achieve and/or improve accessibility while saving time and money. A modular elevator can be constructed with high-quality components and be manufactured in a plant-controlled environment, which results in a high-quality product that greatly minimizes design and engineering costs.

- *Safer Construction*: Standardization of the parts reduces the complications of imparting repeated training to the work force, thereby increasing the technical knowhow of the installation and thereby reducing job site safety hazards.
- *No More Imports*: All the required components can be ordered and stocked as per the quarterly forecast planning based on monthly elevator sales & material consumption. Like reorder point planning, forecast-based planning can be operated using historical values and forecast values and future requirements can be determined via an integrated forecasting program.

The forecast, which calculates future monthly requirements using historical data, can be carried out at regular intervals, which are automatically determined, and are continually adapted to suit monthly sales. This however needs a special storage space in a warehouse/spare parts centre. A compact warehouse can be designed to accommodate a space needed for 6 to 8 full elevators as a minimum.

So, whether it's a new or retrofit project, a modular elevator is the ideal vertical transportation solution.

4 HOW MODULAR DESIGN WORKS

The most popular elevator design is the roped elevator (however now ropes are replaced with flat this steel belts coated with polyurethane (Otis) and even carbon fiber ropes (Kone). Roped electric traction elevators are much more versatile than hydraulic elevators, as well as more efficient. Typically, they also have more safety systems. MRL lifts are energy efficient, require less space, and their operation and reliability are on par with gear-less traction elevators.

4.1 Elevator System Components:

Elevator components, features and operation may vary from one elevator to another. So, this raises the complexity of ordering an elevator, as a result each elevator is always considered as a separate unit for order placement.

A standard elevator always includes the following basic components:

- Car (car sling, upright channels, safety, cab, car door, walls, ceiling & COP)
- Hoistway (guide rails, counterweight, suspension ropes/belts, landing doors, position reference systems, buffers etc.)
- Machine & VF drive systems
- Control systems
- Safety systems

4.2 Possible Design Changes To A Standard Elevator To Achieve A Modular Design:

- *Machine:* Compared with the traditional machines, the PM machine has a high efficiency factor, high efficiency, low starting current, large starting torque, smooth running comfort etc. NdFeB (rare earth) magnets are used to excite the rotor which are extremely small in size, light weight, no gear, low noise, and high reliability. These efficiency and installation aspects provide a new solution to building architects in their desire to provide building

owners with lower operating costs, while maximizing square footage.

- The permanent magnet industry started to see the beginning of the end of serious rare earth shortages in 2011, as new supplies begin to hit the market during 2013 [4]. With their increasing popularity and as they are becoming an industry standard, the cost of the gearless machines has dropped a lot, and a common machine catering for all the loads from 3 passengers to 13 passengers can be designed easily on a single machine.

- *Controller & Drive:* Lift Control System is the system responsible for coordinating all aspects of elevator service such as travel, speed, and acceleration , deceleration, door opening speed and delay, leveling and hall lantern signals. With the advent of the microchip came significant boosts in elevator-control efficiency. Solid-state control technology, which entered the elevator market approximately 20 years ago, is used on all modern elevator systems. So, with availability of modern controllers & drives, a common controller to cater for all the capacities from at least 3 passengers to 13 passengers can be designed easily on a single controller.

- *Elevators rails:* These elevator guide rails are usually used for vertical lifts & elevators to slide up and down safely and smoothly. With high quality available at reasonable prices in China/Europe, guide rails can be obtained at competitive prices.

- *Elevators platforms, slings, uprights & cab:* These form an extremely important part of a modular design elevator. Elevator slings & uprights are mostly of similar structure & dimensions, so just by having these, slings, platforms, and cab panel steel members designed in a well-designed modular structure, they can be assembled to have any dimension of platform and cabs of various standard sizes suitable for a range of elevator capacities.

- *Cab Interiors:* The interiors provide an innovative way to upgrade the visual appearance of any elevator cab. A cab can have many design options. We can have a range of finishes that can include durable plastic laminates, stainless steel, granite, and wood paneling. Interlocking panels stack one on top of the other, making them a snap to install and can be made even easier to replace in the future. Provisions for Toe kick, handrails, and pad hooks can come pre-installed on panels.

- Likewise, every other component of the elevator can be segmented and have a modular design, so when built with segments, different capacities of elevators can be built.

- *Storage:* The storage of these modular components & materials can be easily held in Stacking Racks. Stackable racking system is the most preferred racking system in warehouse storage system since high storage density racking is achieved in the warehouse in terms of cubic storage area of the modular warehouse. Modular stacking racks racking system is even implemented for storage of long items.

- *Use of 3D printing /Parametric Design*: Parameterization allows designers to create models that are flexible and can be changed regularly. All the models made with the help of digital tools like 3D modeling have certain features. They are described by measures such as length, width, depth, orientation, and geometry. The design is based on the relationship between features, parts, and drawings, and it is powered by imagination.

The futuristic 3D/Parametric design also allows a number of benefits:

- **Flexibility –** Using parameterization in design helps to customize work easily. Product creators can build various design iterations and produce many prototypes.
- **Repeatability –** Parametric design techniques provide the opportunity to use parts of previous projects more than once. In addition, they enable split objects into components and try multiple variations.
- **Time-efficiency -**3D printing helps to save time and budget resources instead of using them to acquire machines for manufacture.

5 CONCLUSION

Today's manufacturing organizations are successful if they accurately anticipate market trends and quickly respond to changing customer needs, with innovative products and improved manufacturing processes. Modularity practices (modular products, processes, and organizational architectures) have long been talked about as effective means to cope with demand uncertainty). Since supply chains compete with one another in today's global markets, it would be useful to empirically explore the true influence of modularity-based manufacturing practices on a supply chain's ability to be responsive [10]

The design analysis of a modular elevator has to be better researched in detail by the R&D professionals in the lift industry. R&D should also play a big role not only on the software aspects of the design side but also bring in advanced technological changes in the mechanical components and create robust systems that form the basis for developing a fully modular elevator.

Often, experts are fearful about introducing a new product and costs if that does not involve new age software & IoT technologies in these times. The main hurdle is getting past the "How much does it cost?" and "Are they really needed"? phase.

The engineering and construction sector has been seeing gigantic advancements in building systems & processes, with availability of digital solutions, and the introduction of modular construction. The concept of modularity is also rapidly catching up with other building systems like MEP, HVAC etc.

Modular elevators, if introduced in the market, can bring about a major increase in the market share of the residential elevators and improve the new sales performance of any selling company at least by 10-15%. This will not only improve the sales revenue but also add value to new sales departments' efficiency, enhanced quality, and improved collaboration while satisfying its most important aspect: to help reduce overall operational costs. Once introduced, a modular elevator would see a significant difference in the sales operations, bookings and generate increased revenue to the organization.

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BIOGRAPHICAL DETAILS

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