A CONCEPTUAL LEAN-BASED FRAMEWORK FOR IMPROVING THE ENVIRONMENTAL PERFORMANCE OF READY-MIXED CONCRETE PRODUCTION PROCESSES

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ABSTRACT

The Ready-Mixed Concrete (RMC) industry is one of the fastest growing construction sectors and plays an important role towards infrastructure development. The RMC industry is expected to rise from INR 155-160 billion in 2009 - 2010 to INR 395 - 400 billion in 2014 – 2015 in India. The use of RMC for construction has proved to be advantageous due to its assured quality, accuracy in the mix proportion, faster construction, less workforce and improved workspace utilization. The RMC industry life cycle consists of five major phases namely manufacturing of raw materials, transportation of raw materials to batching plant, batching plant operations, delivery of concrete to site and site activities for placing and compaction. Significant amounts of resources such as materials, energy and water are used during these five phases. The transportation of raw materials and concrete is considered as one of the major sources of energy use and emissions. This study investigates the application of lean concepts for improving the environmental performance of RMC industry operations. First, the current status of RMC industry is presented. Second, a detailed study of resources used during various phases of RMC industry is summarized based on case studies carried out in Chennai. Third, lean concepts relevant for construction to minimize or eliminate non-value adding activities and wastes are discussed. Finally, this study presents a conceptual framework based on lean thinking to improve the environmental performance of RMC industry. This framework can be used to evaluate alternate RMC production scenarios and enhance the decision-making process for better production and environmental performance.

Keywords: *Lean Construction; Ready-Mixed Concrete Production; Sustainable Construction.*

1. DEVELOPMENT OF RMC INDUSTRY IN INDIA

The construction industry in India has been traditionally labour-oriented. This is mainly due to the lack of capital investment, availability of cheap and abundant labour and the highly fragmented nature of the construction sector in the earlier days. However, slowly towards the 1980's, the country saw the advent of liberalisation principles into its economy and this paved the way for large-scale investments in the industrial, infrastructure and agricultural sectors. This led to the increased pace in the mechanisation of the construction industry and to the advent of RMC in India (Jain, 2002).

The use of RMC in the construction industry is significantly advantageous because of many reasons. It assures good quality concrete as well as precise mix proportions of the various raw materials in concrete. It also leads to faster construction, lesser number of labourers, reduced congestion at the work site and improved workspace utilisation (Indian Cement Review, 2014).

Concrete is the most widely used material in the world next to water and in the present scenario, the ready-mixed concrete industry is one of the fastest growing sectors in India. The size of the RMC industry has grown from INR 155-160 billion in 2009-2010 to INR 395-400 billion in 2014-2015 (Goyal, 2012). The main reasons for this exponential growth of the RMC industry in the last few years is

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attributed to the rapid growth in the development of the infrastructure sector, technological advancements and the increase in the per capita consumption of cement and concrete in India.

Ready-mixed concrete arrived in India as early as the 1950's but its use was limited only to large construction projects such as dams, long-span bridges, multi-storey complexes, etc. Its use was mainly made possible with the help of captive plants which were outsourced from other countries as RMC plants were yet to make an impact in the Indian construction sector. In 1974, a techno-economic feasibility study was conducted by the Central Building Research Institute (CBRI), Roorkee, India, which recommended the setting up of RMC plants in the major metropolitan cities of India (Verma *et al.*, 1978). This study led to the establishment of the first RMC plant in 1987. However, the plant did not contribute much to the construction industry as the use of RMC for construction purposes was yet to arrive commercially (Alimchandani, 2007). The first commercial RMC plant was set up in Pune in 1993. In the following year, the Associated Cement Companies Ltd. set up plants in Mumbai and Navi Mumbai. The next decade saw the setting up of a large number of RMC plants in India, predominantly in the metropolitan areas (Jain, 2002).

As per the earliest efforts to count the RMC plants in India, the total number of plants accounted to 27 and was mainly concentrated in the major cities of India (Jain, 2000). In 2001, the number increased to 47 (Jain, 2002) and further increased to 147 by 2005 (Ranganath, 2005). In 2013, the all India commercial statistics of RMC plants amounted to a total of 857 and the latest statistics show that as per January 2015, the total number of RMC plants is 1135 (Manjunathal *et al.*, 2015). Figure 1 shows the rise in the number of RMC plants in India. The development and growth of RMC industry in India and the major milestones are summarized in Table 1.

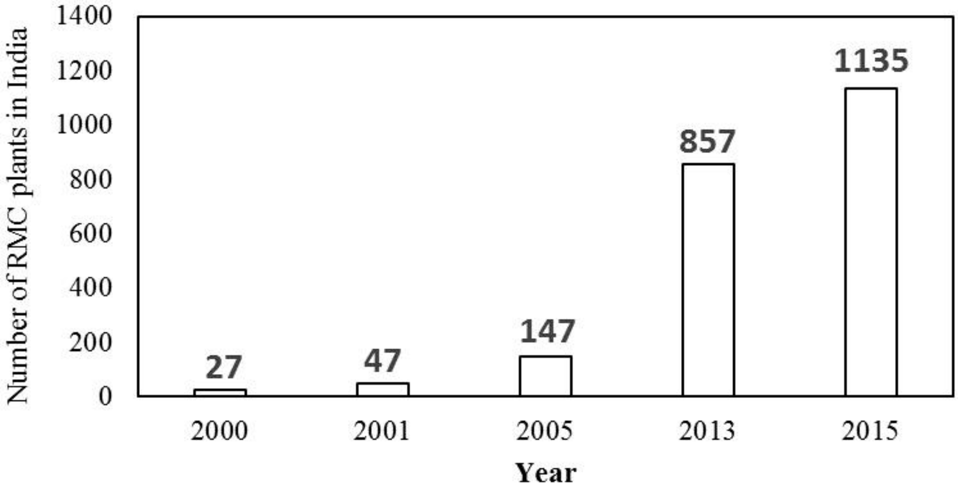

Figure 1: Growth of RMC Plants in India

Also, the Ready-Mixed Concrete Manufacturers' Association (RMCMA) was formed in 2002. It is a non-profit organisation comprising the leading RMC producers in India. The association aims to increase the use of RMC across India as well as to enhance sustainability aspects and conduct research in this field (RMCMA, 2014).

Most of the plants have been set up in the seven large cities of India and they account for 30 - 60 % of the total concrete used in these cities. On an all India basis, RMC accounts for only about 5 % of the total concrete used. However, its use is rapidly increasing in spite of the 12 - 20 % higher cost as compared to the traditional approach of site-mixed concrete (Alimchandani, 2007). On an average, the total concrete market in India is estimated at about 300 million cubic meters annually. Out of this, the RMC plant produced share is about 35 million cubic meters (Goyal, 2012), which is around 12 % of the total concrete production.

Table 1: Major Milestones in the Development and Growth of RMC in India

Year	Event
1950	Introduction of captive plants in India, limited to large-scale construction projects
1974	CBRI recommends setting up RMC plants in major cities of India
1987	Establishment of first RMC plant in India, though it did not contribute commercially
1993	The first commercial RMC plant is set up in Pune
1994	ACC Ltd. Set up two new plants in Mumbai and Navi Mumbai
2000	Earliest efforts to count the RMC plants in India - 27 plants
2001	A total of 47 plants located in the major metropolitan areas
2002	Formation of Ready-Mixed Concrete Manufacturers' Association (RMCMA)
2005	Number of RMC plants increased to 147
2012	Total RMC market estimated at 35 million cubic meters
2013	The total number of plants increased to 857
2015	Estimated number of RMC plants in India - 1135

The use of RMC and the number of RMC plants in India is increasing to such an extent that efforts have to be made to reduce the impact on the environment due to its production processes. This study investigates the application of lean concepts for improving the environmental performance of RMC industry operations. The current status of RMC industry is presented and a detailed study of resources used during the various phases of RMC industry is summarised. The lean concepts relevant for construction to minimize or eliminate non-value adding activities and wastes are discussed. Finally, a framework based on lean thinking is presented to improve the environmental performance of RMC industry.

2. PROCESS MAP FOR RMC PRODUCTION

Four case studies were carried out to develop a detailed understanding of RMC production processes from the extraction of raw materials to activities carried out at site. The RMC plants that were visited are located within 100 kilometres of Chennai, the capital city of Tamil Nadu state in India. Based on these visits, the RMC production related processes are grouped into five major phases namely manufacturing of raw materials, transportation of raw materials to batching plant, operations at the batching plant, delivery of concrete to site using transit-mixer trucks and site operations. Figure 2 shows the details of these phases and the resources used in each phase such as water, fuel, electricity, consumables, equipment, vehicles, instruments and human workforce. The details of the five phases are described below.

2.1. MANUFACTURING OF RAW MATERIALS

The raw materials used for ready-mix concrete production are cement, sand, coarse aggregates, water, admixtures and flyash. Energy is used for manufacturing cement at the cement plant through extraction of raw materials, processing, clinker production, grinding and packaging. Cement is produced mainly from limestone and clay along with smaller amounts of gypsum. Coal and coke are used for burning cement clinkers and oil is used for lubrication. Sand is usually obtained from the river sources. Usually, 20 mm and 12/10 mm coarse aggregates are used for concrete production. Manufactured sand is used in some cases when the river sand is not available. Flyash is obtained as a by-product from thermal power plants.

The admixtures are produced from a wide variety of chemicals. Water is usually obtained from a natural source.

2.2. TRANSPORTATION OF RAW MATERIALS TO BATCHING PLANT

The raw materials required for ready-mixed concrete production are transported to the batching plant using trucks. Cement and flyash are stored in huge silos at the batching plant. The coarse and fine aggregates are stored in their respective storage yards. The admixtures are transported to the plant in cylindrical barrels which are connected to the batching plant mixer. Water is brought to the plant in tankers and are filled in the water tanks.

2.3. BATCHING PLANT OPERATIONS

The batching plant is usually fully automated and is run by diesel or electricity. The major sources of energy consumption include the diesel generator, site office operations, loader used for handling aggregates from the storage yard to automated belt conveyor and trucks used by staff members. The batching plant is able to produce different grades of concrete as well as special types of concrete such as self-compacting concrete. The mix proportions are already stored into the automated control systems of the batching plant. The mixer used in the plant is either a pan mixer or a twin shaft mixer.

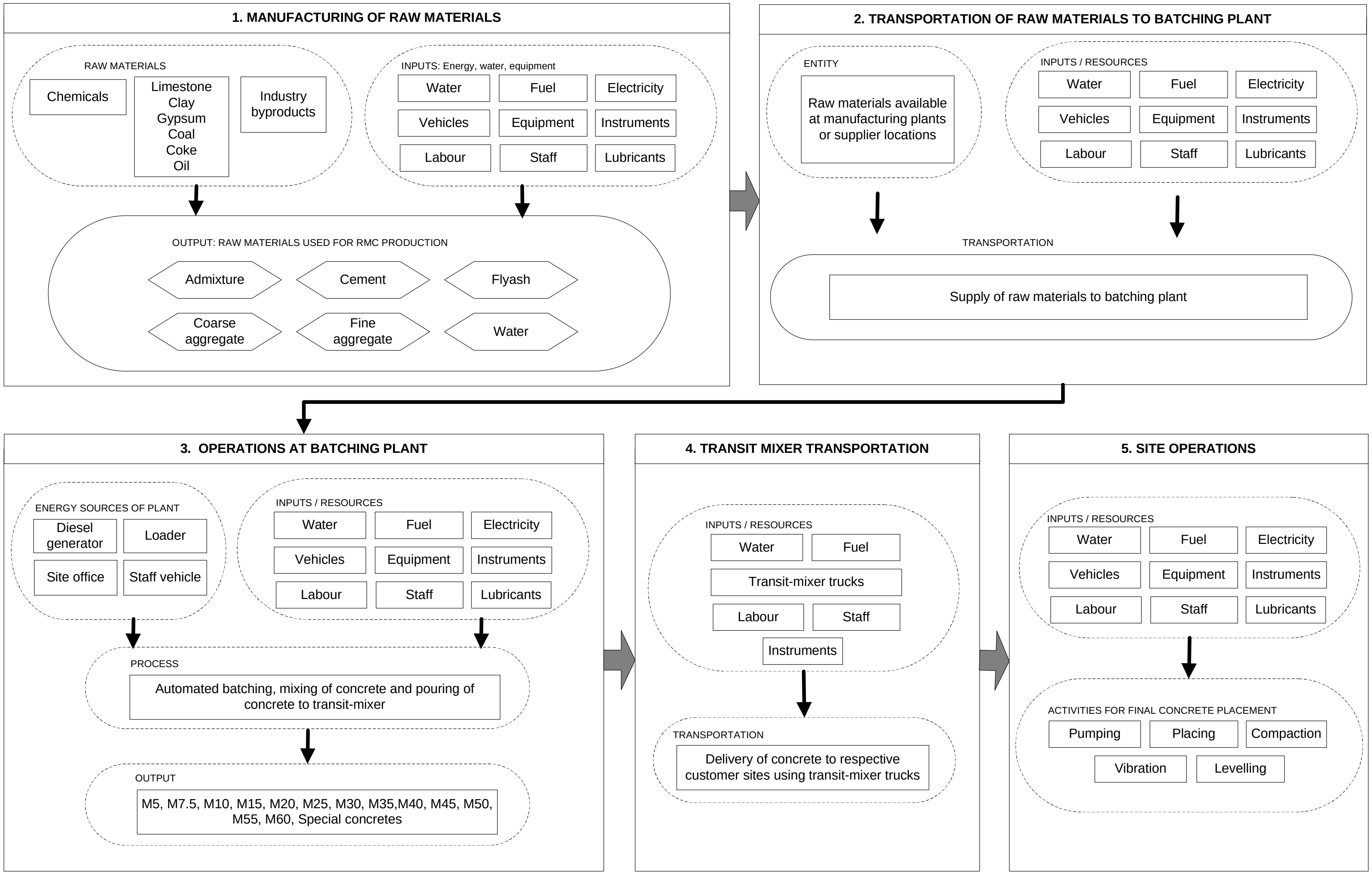

Figure 2: Process Map of RMC Production

2.4. TRANSPORTATION OF RMC USING TRANSIT MIXER

The batched concrete is fed into the transit-mixer trucks which are transported to the respective customer sites. The total capacity of the transit mixers are 7 cum. The final mixing of the concrete is performed in the rotating drums of the transit-mixer trucks. For the best properties of concrete to be maintained, the concrete should reach the site within a maximum time of 2 hours from the time of batching. Traffic usually hinders the smooth transportation of transit-mixer trucks, especially in the major cities.

2.5. SITE OPERATIONS

Once the transit mixer reaches the customer site, the concrete is then pumped to the required location using a concrete pump. The placed concrete is further levelled and compacted for its effective placement. The surface is then given the final finishing using appropriate tools to get a smooth appearance of concrete before the curing is done. In most cases in India, the RMC supplier takes care of pumping the concrete at site while most of the other activities are under the control of the building contractor.

3. REVIEW OF LEAN CONCEPTS AND TOOLS

Lean thinking was originally developed in the 1930's from the idea of elimination of waste in production systems. It was introduced by Henry Ford and was popularly known as the Toyota Production system. Lean thinking was finally simplified into five main principles: specify value, identify the steps in the value stream, continuous flow, pull production and pursue perfection for continuous improvement (Womack and Jones, 1996). Over production, over-processing, rework, excess inventory, waiting, transportation and excessive motion are the major sources of waste. Once the source of waste is identified, lean approach uses various concepts and tools for the elimination of wastes, thereby making the system more productive. Some of the lean concepts/ tools are discussed below (Marhani *et al.*, 2013):

- Just-in-Time (JIT): It is a Japanese philosophy applied in manufacturing which involves having right items of right quality and quantity at the right place and right time.
- Continuous improvement: It is a systematic approach to gradual, orderly and continuous improvement of a production system.
- Total Quality Management (TQM): The management of quality at every stage of operations from planning to design through continual process monitoring for process improvement.
- Work Standardisation: Standardisation of work ensures that each job is organised and carried out in the most effective manner for the elimination of waste.
- Total Productive Maintenance (TPM): TPM is a set of tools, which when implemented in an organisation as a whole gives the best utilization of machines with least disruption of production.
- Value Stream Mapping (VSM): It is a lean-management tool for analysing the current state and designing a future state for a series of events after detecting and eliminating the non-value adding activities. It also optimizes the value adding activities.
- Huddle Meetings: Start-of-the-day meetings of all personnel to review the work to be done that day.
- 5S (Workplace organisation): One of the most effective tools for continuous improvement is 5S which consists of sort, straighten, sweep and clean, systemise and standardise for effective waste reduction.

3.1. LEAN CONSTRUCTION

In 1992, the lean manufacturing principles were introduced into the construction industry by Koskela (1992) for better productivity. Lean construction is believed to be particularly useful on complex, uncertain and quick projects. The main objective is to maximize the value and minimise waste (Lean Construction Institute, 2012). This allows companies to reduce cost, eliminate waste and deliver projects in time (Lim, 2008). A new flow planning and controlling system, known as the Last Planner System (LPS) introduced fundamental changes in the way construction projects are planned and controlled (Ballard, 2000; Ballard and Howell, 1997). In LPS, the sequences of implementation sets up an efficient schedule planning framework through a pull technique, which shapes work flow, sequence, and rate; matches work flow and capacity; develops methods for executing work; and improves communications between trades. Table 2 presents a review of lean construction case studies which used Last Planner System and other lean concepts such as Value Stream Mapping.

Table 2: Summary of Lean Construction Case Studies

Project	Country	Benefits	Implementation Phase (Technique)	Reference
Hospital building project	USA	Increased work plan reliability	Construction phase (LPS)	Ballard (2000)
Hospital building project	USA	Improved work planning ability	Design phase (LPS)	Hamzeh *et al.* (2009)
Medical center project	Chile	Efficient identification and measurement of waste resources	Construction phase (VSM)	Rosenbaum *et al.* (2013)
New town development	USA	Better resource levelling and Improved work planning ability	Design phase (LPS)	Ballard *et al.* (2009)
Housing project	Ecuador	Improved project performance and increased work plan reliability	Construction phase (LPS)	Fiallo and Revelo (2002)
Apartment buildings	Israel	Reduced batch size, Work in Progress (WIP) is controlled, reduced cycle times	Construction phase (VSM)	Sacks and Goldin (2007)
Residential building	Brazil	Improved look-ahead planning	Construction phase (LPS)	Kemmer *et al.* (2007)
Central bus station project	Peru	Reduced project delivery time and production time	Design phase (LPS)	Arbulu *et al.* (2006)
Subway project	South Korea	Improved informational transparency and reduced procurement cost	Construction phase (LPS)	Kim and Jang (2005)
Airport building	UK	Reduced cost	Supply chain management (LPS)	Ballard *et al.* (2007)
Parking garage	USA	Increased profit	Construction phase (LPS)	Salem *et al.* (2005)
School building	Denmark	Reduced batch size	Construction phase (LPS)	Nielsen and Thomassen (2004)
Administration building	Saudi Arabia	Improvement in quality of work practice, enhancement in managerial practices	Construction phase (LPS)	Sehaimi *et al.* (2009)
Industrial bridge construction	Sweden	Reduced cost, physical loads and improved safety	Construction phase (LPS)	Simonsson and Emborg (2007)
Industrial building	Brazil	Improved supply chain integration	Construction phase (LPS)	Sterzi *et al.* (2007)

4. Framework for the Application of Lean Concepts in the RMC Industry

This section depicts that the application of lean principles in the different phases of RMC industry could greatly influence the time, cost and the environmental performance of the production processes. A framework is presented based on the visits undertaken to RMC plants in Chennai. Figure 3 presents a lean-based framework for improving the environmental performance of RMC industry. The framework suggests that lean concepts can be used for improving the production performance as well as the environmental efficiency. The five phases of RMC production are taken into consideration and activities that enhance the environmental and production performance are presented. Each proposed action is linked with a lean concept recommending that the lean thinking in the RMC industry can lead to better production and environmental benefits.

4.1. Manufacturing of Raw Materials

The energy consumption and emissions due to manufacturing of raw materials can be reduced by applying the relevant lean concepts. The raw material inventories should be maintained such that they are available only when required keeping the over-production of the materials at check. The over-processing of raw materials should be eliminated by all means as this leads to additional usage of energy. The quality and safety should be under check and defects should be eliminated to avoid rework. Moreover, in keeping with the concept of sustainability from the design stage itself, the use of locally available raw materials and recycled materials should be encouraged.

4.2. Supply of Raw Materials to Batching Plant and Transportation of RMC by Transit Mixers

The use of large capacity trucks for raw material transportation to the batching plant as well as the usage of optimum number of trucks will keep a check on the number of trips to the batching plant, which in turn will conserve the fuel consumption substantially. The trucks should be managed in such a way that the waiting time and queuing of each truck should be minimised as much as possible as this will decrease fuel wastage. Moreover, the proper maintenance and repairs of all vehicles and equipment should be carried out regularly. The skill of the driver is also an important factor related to the fuel use of transit truck mixers.

4.3. Batching Plant Operations

The performance of batching plant can be improved through the application of lean concepts which could reduce the impacts on the environment. One of the main requirements is to schedule the batching of concrete according to the customer needs. This could be done by setting of adequate milestones for each RMC company to reach their target production. Weekly work plans along with start-of-the-day meetings will be helpful to plan ahead for better efficiency of the plant. It will also lead to increased knowledge and communication among the workforce at the batching plant. Incorporating the use of safety and mobile signs could lead to better team effort during batching plant operation. The use of the loader for aggregate transportation should be controlled in order to maintain the number of times it is used, thereby reducing the fuel consumption.

4.4. Site Operations

The operations at the site include the usage of a large number of equipment and vehicles. These should be maintained regularly in order to improve the overall efficiency of site activities. During the vibration of concrete, care should be taken such that it is not over-compacted. Regular safety and quality checks should be ensured for improving the productivity rate and reducing the defects. Also, in case of exceeding the transit mixer delivery time, the usage of higher grade concrete for lower grade strength requirement is also followed as it will not lead to the wastage of batched concrete.

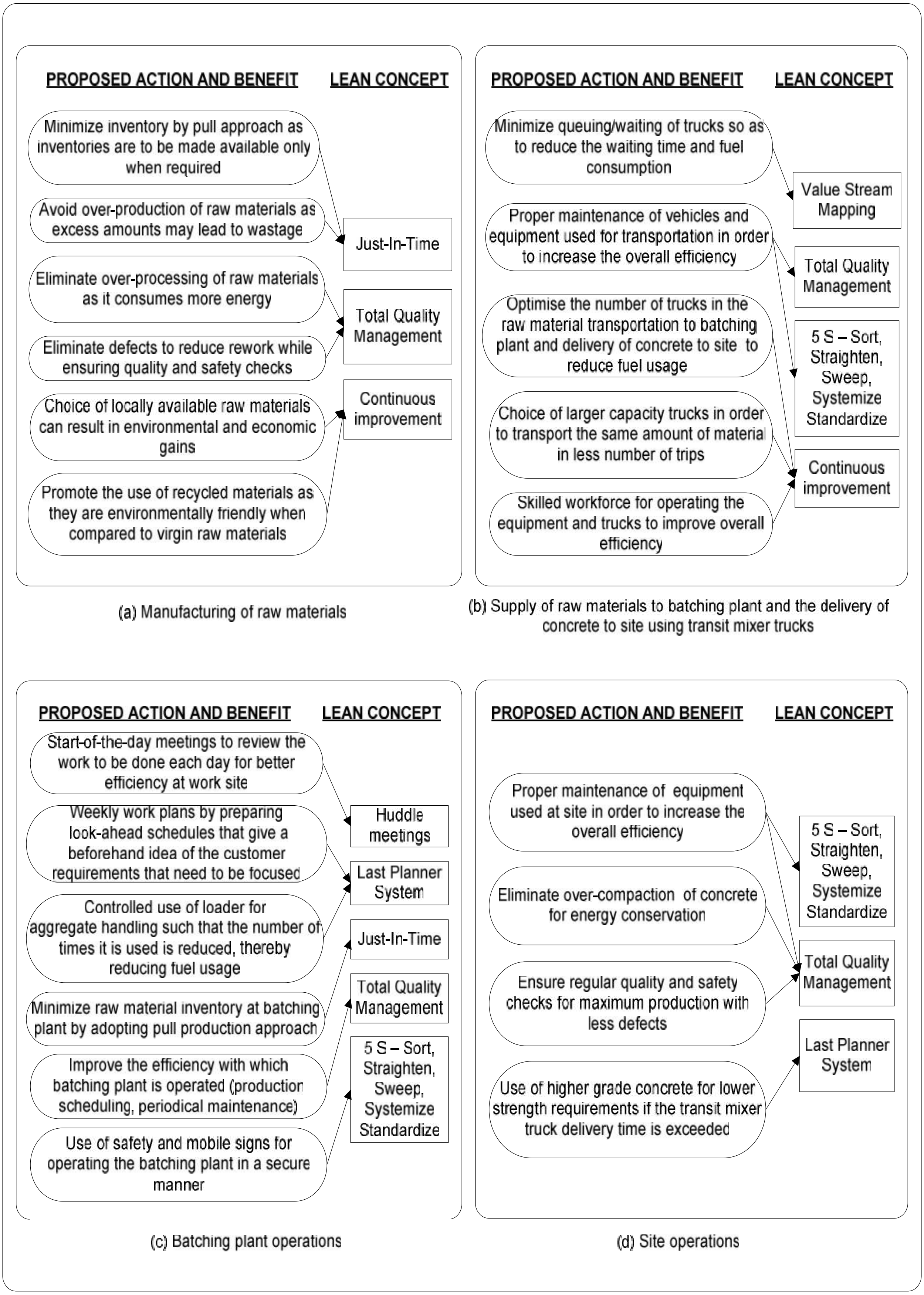

Figure 3: Lean-based Framework for Improving the Environmental Performance of RMC Industry

5. CONCLUSION

This study presents a review of the status of RMC industry in India and a process map documenting the details of major phases of RMC industry from raw materials production to site operations. Due to the growing demand of RMC and the increased environmental concern today, a lean-based framework is presented for improving the environmental performance of the RMC industry. Further studies can focus on gathering field data related to energy use and developing a simulation model for evaluating alternate production and construction scenarios to assess the performance in terms of cycle time, energy footprint and carbon footprint. The simulation-based model will also be useful to study the effect of lean concepts on production performance.

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