Evaluation of the use of prefabricated bridge elements with Design for Manufacture and Assembly (DfMA) criteria

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Abstract. The increasing need for bridge infrastructure in Indonesia requires an efficient and lean construction process. The aim of this research to evaluate the use of precast concrete elements on bridges based on the Design for Manufacture and Assembly (DfMA) criteria. DfMA is a principle design that considers the process of manufacture and assembly components based on the following criteria, i.e., simplicity of design, number of components, standardization on elements or material and ease of handling. Analytical Hierarchy Process (AHP) is used to determine the weights for each criteria. Data were collected through observations on a bridge project, interviews with engineers and questionnaires. A typical girder and slab bridge is used as an object for DfMA-based evaluation. The results of evaluation design of prefabricated components to recommend some that are suitable for use in bridge construction. The last case study was taken to one of the bridge construction projects on the newly completed highway is done to identify the prefabricated components used. Bridge analysis and re-design are carried out with the DfMA concept, including costs incurred, resource scheduling and discussions of project risk. The results of analysis with simulation design giving efficiency 28.83% simplicity of design; 8.74% number of components and standardization on elements or materials; 25% ease of handling; 51.53% assembly time; 23.39% cost of work and 18.87% duration time. Finally, the level of risk of work received such as weather conditions and work safety is reduced. In closing, recommendations were given for further DfMA development.

1 Preliminary

The availability of infrastructure is an important and vital aspect to accelerate the national development process. Increasing population parallel with demand roads and bridges. On the traditional bridge construction it is often criticized for being inefficient and unsafe [1]. To overcome this through the Accelerated Bridge Construction (ABC) program, which is a construction management system with the use of more prefabricated technology in the implementation process [2]. Applying prefabrication with the main characteristics of assembly on bridge elements is an effort to standardize products or components through the factory [3].

The design stage plays a crucial role in determining the resources, costs, time and others for the production and assembly process. One way to evaluate the design of a product is with the Design for Manufacture and Assembly (DfMA). Some DFMA requirements can be used at various levels of complexity [4].

2 Literature review

2.1 Standardization

Standardization is the use of building components with a standard size of an integrated system that is carried out before the design stage including the installation process which has its own functions, models, sizes, procedures and other issues [5]. Standardization in the construction field is divided into two, i.e standardized products or components and also standardized processes [3]. Standardized products are to making various components needed in the plant for assembly at the construction site. While standardized processes by developing a process to handle unique aspects of a particular product in a location.

2.2 Industrialization

Industrialization is the process of development production system technology and its implementation using the standardization of design, mechanization and automation on site, computer equipment and mass
production of building elements [6]. Three main principles industrialization of construction are standardization, prefabrication and building systems [7].

Prefabrication is a technology in rapid construction of building by produce the main elements from a different place and delivered to location for installation [8]. Characteristics of prefabricated buildings are design standardization, industrial production and assembly construction [9]. Prefabrication is one of the answers in solve current building demands by re-produce products on a large scale for inventory and the speed of the building process [10].

2.3 Definition, type and development of bridges in Indonesia

Bridge is a structure built connecting two different locations, or facilitate traffic flow and across the lowlands. Based on constituent materials, bridges are divided into four type, i.e., wooden, steel, concrete and composite. There are currently 93000 bridges (1138 km) in Indonesia which consists of 72000 (734 km) in district or city and province roads with 21000 (404 km) in national roads which is dominated by mainly standard bridge, i.e., girder 51% (comparison materials using concrete and steel are 75%: 25%), culvert 7%, truss 32% and others 10% [11].

The development of modern bridge construction at present meets the following requirements [12]:
- Achievement of connections between a composite steel and continous concrete for the elements.
- Minimized joints.
- Reduces installation time of elements.
- Minimize the problem of tolerance between concrete and steel materials.
- Suitable stiffness when receiving moments and deflection.

2.4 Design for Manufacture and Assembly

DfMA is a simultaneous design and engineering approach where the parts are manufactured and (sub-) assembled in a factory or warehouse, before being delivered to a construction site for installation [13]. DfMA using prefabricated techniques can provide benefits on construction schedules, costs, labour, safety and quality. The DfMA approach requires a change in the relationship between design and construction. The design focuses on the method which the project will be completed, where the possibility of using components is produced outside the site and logistics and assembly efficiency [14].

The main purpose of the DFMA is to assist designers in optimizing and increasing the success rate of prefabricated building design by integrating other stages of knowledge and information facilities into the design stage [9].

2.5 Relationship DfMA and lean construction

Concepts lean construction is the production system adopted from the Japanese Toyota company with the principle that customer focus, culture, workplace organization and standardization, minimizing waste, continuous improvement and building quality [15]. Lean methods and tools are generally used for repetition of products such as the low variety of product series with large quantities [16]. The principle of lean production is also potentially implemented with the use of DfMA by simplifying the design and standardization of parts compared to conventional production systems which often occur rapidly [17]. The construction industry can be said to be a manufacturing process where the unification of materials forms a component for final installation. Lean construction is a major way to prevent large amounts of information lost in planning, factory production and development [18].

3 Research methodology

In this study the primary data from questionnaires, interviews and observation in the field. Whereas secondary data from catalogs of precast concrete product and the documents of bridge project. Respondents in this study are engineers who work on precast concrete companies. The first step of the study is given the DfMA category for bridges based on references which related to the standardized of bridge design in Indonesia where show on Table 1.

Table 1. Identification of DfMA criteria and standardized of bridge design

| DfMA criteria (8); (11) | Standardized of bridge design (10) |
|------------------------|-----------------------------------|
| Simplicity of design   | SS D I M R E C A L |
| Number of components   | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
| Standardization on elements or material | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |
| Ease of handling       | ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ |

SS = Structural Safety; D = Durability; I = Inspectability, M = Maintability; R = Rideability, E = Economical; C = Constructability; A = Aesthetics; L = Environment
3.1 The assessment of precast products design

The assessment product used in this study where the selection of precast concrete product designs on the girder and slab bridge elements that are often used so that evaluations can be carried out. These elements, are the main components in the building structure of the bridge. Table 2 shows the mapping of precast concrete products for bridge elements i.e. girder and slab. These products are assessed by the designers using the predefined DfMA criteria. In Figure 1 shows the hierarchy structure of an alternative product evaluation scheme consisting of four DfMA criteria combined with types of precast concrete products for the girder and slab bridge elements.

From the data obtained, then to measure the weight of the criteria and find out the final design score of each product, an analysis is done using analytical hierarchy process.

3.2 Evaluation case study

Evaluation was carried out on the construction of a bridge. The process includes identifying bridge components, redesign the bridge using precast product development, DfMA analysis, comparing the amount of costs, implementation time and knowing the impact of risk that happened.

4 Data analysis and discussion

4.1 Analytical hierarchy process

Table 3. Value geomean of each criteria

| Criteria     | R1, R2, R3, R4, R5, R6, R7, R8 |
|--------------|---------------------------------|
| DS           | 1.00                            |
| JKK          | 1.28                            |
| SEM          | 0.49                            |
| KP           | 0.56                            |
| SD           | 0.78                            |
| NC           | 1.00                            |
| SEM          | 0.31                            |
| EH           | 0.68                            |
| Average      | 0.62                            |

Table 4. Normal pairwise comparison matrix

| Criteria | SD   | NC   | SEM  | EH   | Weight | Average |
|----------|------|------|------|------|--------|---------|
| SD       | 0.18 | 0.78 | 0.24 | 0.09 | 0.68   | 0.17    |
| NC       | 0.14 | 0.13 | 0.15 | 0.09 | 0.51   | 0.13    |
| SEM      | 0.36 | 0.44 | 0.49 | 0.66 | 1.96   | 0.49    |
| EH       | 0.32 | 0.26 | 0.12 | 0.16 | 0.86   | 0.21    |

Average calculation the geometric (geomean) of each criterion is presented in table 3, while the normal matrix analysis of paired comparisons includes calculating the weight of the most influential criteria and the average values shown in table 4.

From the results of the weighting criteria, the order of weight values from highest to lowest is
standardization on elements or materials - ease of handling - simplicity design – number of components.

![Fig. 3. Radar diagram](image)

**Table 5. The ranking of product design**

| Criteria | Weight | Products | Value | Score | Value | Score | Value | Score | Value | Score | Value | Score | Value | Score |
|----------|--------|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| DS       | 0,17   | PC I Girder | 3,75  | 0,64  | 3,50  | 0,59  | 3,00  | 0,51  | 3,25  | 0,55  | 3,63  | 0,61  | 3,00  | 0,51  |
| JKK      | 0,13   | PC Voided Slab | 3,38  | 0,43  | 3,25  | 0,41  | 3,00  | 0,38  | 3,38  | 0,43  | 3,13  | 0,40  | 3,13  | 0,40  |
| SEM      | 0,49   | PC T Girder  | 3,75  | 1,83  | 4,00  | 1,96  | 3,63  | 1,77  | 3,75  | 1,83  | 3,13  | 1,53  | 3,88  | 1,90  |
| KP       | 0,21   | PC Full Slab  | 3,25  | 0,70  | 3,38  | 0,72  | 3,13  | 0,67  | 3,75  | 0,80  | 3,00  | 0,64  | 3,13  | 0,67  |
|          |        | Total       | 3,60  |       | 3,69  |       | 3,33  |       | 3,62  |       | 3,18  |       | 3,47  |       |
|          |        | Ranking     | 3     | 1     | 6     | 2     | 7     | 4     | 5     |       |       |       |       |       |

Overall, from the results of the analysis and evaluation, the design values of each precast concrete product for the girder and bridge floor elements from the largest to the smallest respectively are PC Voided Slab - PC Full Slab - PC I Girder - PC Double Tee Slab - PC U Girder - PC T Girder - PC Box Girder. This means that the designs of existing precast products, especially PC Voided Slab, are the closest to the principle Design for Manufacture and Assembly (DfMA). But it does not rule out the possibility that the value of other precast products can be better than those that already exist or are even superior. This happens if the designers take the initiative to redesign the product in question, considering the value obtained is not much different. With the design change, it is hoped that it can create new types of products that make the production and assembly process easier in the factory or project environment.

### 4.2 Sanjoyo River Bridge

The construction of Sanjoyo River Bridge is part of the work package for construction of the Semarang-Solo toll road phase II Bawen-Solo section III Bawen-Salatiga located at sta. 34 + 321,870 to sta. 34 + 498,735 and the administrative area is located in Sukoharjo urban village, Pabelan sub-district, Semarang regency, Central Java province. The design of bridge is fully entrusted to PT. Citra Strada by adopting the DfMA approach on several components of the upper structure, while the work process is carried out by PT. PP (Persero) Tbk with a period time of 1.1 years. The design of bridge to be slightly curved with structure type monolith precast girder. The span of bridge is divided into five, i.e. 25,6 + 40,8 + 40,8 + 40,8 + 25,6 = 173,6 m and a total width of 25,2 m. At each span each rests on the bearing where the tip of the bridge is above the abutment, while the pedestal in the span is being used by the crosshead of the pillars as a support for the main structure. The type of bridge foundation itself are bor piles on both abutments, while the pillars use a combination of foundation bor piles and footing.

In order to obtain an economical bridge design, it is necessary to re-select the girder cross section. In this case the dimensions of the beam determine efficiency of the components in the bridge structure, because it functions as a link to the main work loads on the upper structure to the lower structure. On bridges with simple spans, beam eccentricity is proportional to the prestressing force required where the moment acting in the middle can determine the design. Therefore due to greater eccentricity, more concrete area is needed on the top of the beam. This is recommended using “T” or “I” beam section with wide wing characteristics. Both types of beams have a full cross-sectional standard at the end due to avoiding a zero value moment, increasing shear capacity and preventing failure in the anchorage area.

![Fig. 4. Dimensions of the BH Girder](image)
An alternative design for development the type of girder is now also carried out on one of the precast products that have a “T” section that is BH Girder. BH Girder is a combination of two types precast product, Bulb Tee Girder and Half Slab [20]. The principle of BH Girder in addition to reducing the amount of anchorage on the end of the beam and moving it to the middle. This product has several blisters, especially on the body of beam with a pre-stressed internal system. Half Slab on BH Girder has the principle of reducing the amount of thickness of the slab and also serves as a channel for the load to the girder so that it is more evenly distributed.

### 4.2.1 Analysis of simplicity design

The design of bridge uses standard sizes BH Girder with a span configuration of $57.8 + 58 + 57.8 = 173.6$ m. The distance between girders is optimized to 2.5 m. Dimensions BH Girder i.e.; 2.3 m high; widths upper flange 2.2 m and below 1.4 m. Half Slab on BH Girder is designed as thickness 13 cm. K-850 concrete quality specifications are used in girder to support bridge service life with several planning assumptions. Slab has a height of 15 cm and uses K-350 concrete quality with a main reinforcement using D22 - 120 mm, while for reinforcement using D16 - 120 mm. Slab divided into 3 rigid pavement segments according to the distribution of bridge span and includes one way slab type.

### 4.2.2 Analysis of components quantity and the use of standardization on elements or material

The difference in design of a bridge element also results in changes in the amount of constituent components and standardization of elements or materials. The bridge component consists of several sets of materials arranged to form a bridge element.

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**Table 6. Amount of elements**

| Elements       | Material type       | Symbol of Unit | Design | Simulations | Difference | Efficiency (%) |
|---------------|--------------------|----------------|--------|-------------|------------|----------------|
| Bearing       | Reinforced concrete | m<sup>2</sup>  | 4.83   | 12.10       | (7.26)     | (150)          |
|               | Fabrication of bearing | unit          | 90.00  | 60.00       | 30.00      | 33.33          |
|               | Fabrication of rubber sheet | m<sup>2</sup> | 62.92  | -           | 62.92      | 100.00         |
| Diaphragm     | Precast concrete   | unit          | 341.00 | 243.00      | 98.00      | 28.74          |
| Girder        | Precast concrete   | unit          | 60.00  | 30.00       | 30.00      | 50.00          |
| Slab          | Fabrication of spandec | m<sup>2</sup> | 255.84 | -           | 255.84     | 100.00         |
|               | Fabrication of deck drain | unit | 78.00 | 68.00       | 10.00      | 12.82          |
|               | Reinforced concrete | m<sup>2</sup> | 1093.68 | 656.21      | 262.48     | 24.00          |
| Expansion joint | Fabrication       | m            | 152.50 | 105.00      | 47.50      | 31.15          |

Finally, for diaphragm beams in the transverse position designed with a system precast that has a length of 2,28 m; width of 2 m and a thickness of 0.2 m. Each span has 90 plate pieces with some stressing bars. In table 6 shows the needs of the elements of each design. The five elements in the simulation design have efficiency of 28.83% compared to existing design.

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**Table 7. Comparison of components quantity**

| Elements       | Components              | Symbol of Unit | Design | Simulations | Difference | Efficiency (%) |
|---------------|-------------------------|----------------|--------|-------------|------------|----------------|
| Bearer        | Deformed bar            | kg             | 1108.65 | 2784.02     | (1675.37)  | (151.12)       |
|               | Metal bearing shoe type A | unit          | 24.00  | 60.00       | (36.00)    | (150.00)       |
|               | Bearing pad size (30x35x0.36 cm) | unit | 12.00  | -           | 12.00      | 100.00         |
|               | Bearing pad size (35x40x0.39 cm) | unit | 48.00  | -           | 48.00      | 100.00         |
|               | Bearing pad size (30x35x0.36 cm) | unit | 6.00   | -           | 6.00       | 100.00         |
|               | Rubber sheet            | m<sup>2</sup>  | 62.92  | -           | 62.92      | 100.00         |
|               | Mortar and grouting     | m<sup>2</sup>  | 4.84   | 12.01       | (7.26)     | (150.00)       |
| Diaphragm     | Round bar               | kg             | 171.03 | 452.45      | (281.42)   | (164.54)       |
|               | Deformed bar            | kg             | 25464.57 | 39873.01    | (14408.44) | (56.58)        |
|               | Ducting                 | bh             | 682.00 | 486.00      | 196.00     | 28.74          |
|               | Concrete class B1       | m<sup>3</sup>  | 148.85 | 173.60      | (24.75)    | (16.63)        |
|               | Bar                     | unit           | 31.00  | 27.00       | 4.00       | 12.90          |
|               | Widges plate and accessories | unit | 62.00  | 42.00       | 20.00      | 32.26          |
| Girder        | Deformed bar            | kg             | 314,613.51 | 347,925.72 | (33312.21) | (10.59)        |
|               | Bursting steel          | unit           | 216.00 | 150.00      | 66.00      | 30.56          |
|               | Spiral                  | unit           | 216.00 | 150.00      | 66.00      | 30.56          |
|               | Upper dowel             | unit           | 21180.00 | 15390.90    | 5790.00    | 27.34          |
|               | Tendon pipe             | point          | 1080.00 | 900.00      | 180.00     | 16.67          |
|               | Blister                 | point          | 360.00 | 300.00      | 60.00      | 16.67          |
|               | Concrete class A1       | m<sup>3</sup>  | 1394.12 | 2283.19     | (889.07)   | (63.77)        |
|               | Shear connector between segments | unit | 504.00 | 0.00        | 504.00     | 100.00         |
|               | Adhesive connection between segments | point | 720.00 | 900.00      | (180.00)   | (25.00)        |
|               | Strand                  | unit           | 216.00 | 150.00      | 66.00      | 30.56          |
4.2.3 Analysis ease of handling

One of the principles of DFMA is to reduce the amount of completion of a final product. The steps of production and assembly of a bridge element are various activities from the manufacturing process to the interrelated installation. The steps of bridge construction work are focused on assembly lines in this case the construction project as the estuary from the completion of a final product.

Table 8. List the detail of works

| Work items                        | ED  | SD |
|-----------------------------------|-----|----|
| Bearing pad size, (300x350x36 mm) | A   | -  |
| Bearing pad size (350x400x39 mm)  | B   | -  |
| Bearing pad size (450x450x39 mm)  | C   | -  |
| Rubber sheet                      | D   | -  |
| Metal bearing shoe type A          | E   | A  |
| PC I Girder span 40.8 m (H = 160 cm) | F | -  |
| PC I Girder span 25.6 m (H = 210 cm) | G | -  |
| BH Girder span 58 m (H = 230 cm)  | -   | B  |
| Round bar                         | H   | C  |
| Concrete class B-1-2 (diaphragm)  | I   | D  |
| Plate precast (concrete plate)     | J   | -  |
| Deform bar                        | K   | E  |
| Concrete class B-1-1 (RC deck slab)| L   | F  |
| Expansion joint type C2            | M   | G  |
| Expansion joint type G             | N   | H  |

ED = Existing design; SD = Simulation design

The use of standardization is a dimension, guideline and something that is repetitive to an element or material. Comparison of the quantity of components between existing design and simulation design are presented in Table 7. Based on the results mentioned, the use of BH Girder in the simulation design resulted in reduced volume of material in each elements, with savings of 8.74% compared to the existing design using PC I Girder.

4.2.4 Analysis of productivity and DFA Index

Design for assembly (DFA) index is a result of multiplication between the sum of the minimum theoretical parts and the basic assembly time of each component divided by the total installation time as a whole. At this stage the DFA index is focused on the time of installation of the girder bridge. Analysis of productivity and time duration is carried out through field observations with the intention that the data obtained is more accurate and in accordance with the actual conditions. Before carrying out the analysis phase, it is necessary to look back at the method of installing the bridge girder in the existing design i.e crane and gantry system. Then one of them is chosen as a comparison.

Table 9. Assembly time of crane methods

| Steps            | Time (minutes) |
|------------------|----------------|
| Preparation      | 13.60          |
| Lifting          | 0.21           |
| Swing            | 0.70           |
| Placement at position | 43.4  |
| Return to location of loading | 12.00 |
| Σ                | 69.91          |

The result of calculation of each time of installation stage of the girder using the crane is shown in table 9. The total time for the assembly process of one girder unit is 69.91 minutes with the average time to the five steps is 13.98 minutes. By considering the next stage, namely the installation of diaphragm beam, normal working time 8
hours (480 minutes/day) and other activities on the project after installation of the girder, the daily productivity is taken 2 units.

Table 10. Assembly time of gantry method

| Steps                  | Tools | Time (minutes) |
|------------------------|-------|----------------|
| Preparation            | Crane | 13.60          |
| Transportation         | Crane | 0.21           |
| Swing                  | Crane | 0.70           |
| Placements of launcher | Crane | 8.30           |
| Attribution for decision | Gantry | 2.30       |
| Cargo and decreased    | Gantry | 32.10          |
| Release                | Gantry | 1.20           |
| Return to the location of loading | Gantry | 6.40 |
| Σ                      |       | 64.81          |

In table 10 shows the duration time of each girder installation steps using launching gantry method which consists of two main tools i.e. crane and gantry. Total time for the assembly of one girder unit is 64.81 minutes, while the average value has 8.1 minutes. In launching gantry method, activity under span of bridge can be carried out smoothly because it does not prevent crane method from requiring enough a large area. From these considerations, the daily productivity of the girder installation is 3 units.

Table 11. Calculation DfA Index

| Design     | Method | Parameters |
|------------|--------|------------|
| Existing   | Crane  | p = 69.905 |
|            | Gantry | q = 11.041 |
| Simulation | Gantry | r = 1677.731 |
|            | Gantry | s = 0.158  |
|            | Gantry | t = 0.0164 |

4.2.5 Analysis of time

Analysis of time functions to determine the number of settlement days work. Bar chart is used to measure the calculation of the duration of the activity. Determination of the number of days for each work item based on several parameters such as work volume, method of works, number of stages of parts, type of material used, weather, location and others. Overall for the duration of the work execution time there is efficiency 10 days or 18.87%.

Fig. 7. Bar chart the works of existing design

Fig. 8. Bar chart the works of simulation design

4.2.6 Analysis of cost

Cost analysis is done to determine the total price of each work item. The calculation is focused on the direct costs of work obtained from the multiplication between the volume of work and the unit price. For unit prices that are not in the bill of quantity such as BH girder, then the technical analysis of unit prices is done manually.

Table 12 shows total cost the works of existing design is Rp. 24,241,735,772.02 while the works of simulation design is Rp. 18,571,014,244.83. One of the works that is the factor that causes the difference in the costs is the girder with a value of Rp. 221,518,1274.21. Based on these results overall it can be concluded that there is a reduction in costs with a percentage of 23.39%.

Table 12. Total cost of concrete structure work

| Works                        | Design | Difference (Rp.) | Efficiency (%) |
|------------------------------|--------|------------------|----------------|
| Concrete class B-1-1 (RC deck slab) | 1894253760.00 | 1136552256.00 | 757701504.00 | 40.00 |
| Concrete class B-1-2 (Diaphragm)    | 284265785.51 | 331527600.22 | 47261814.71 | 16.63 |
| Round bar                      | 1067492.60 | 4490566.25 | 2793073.65 | 164.54 |
| Deformed bar                   | 5340913993.25 | 3128998652.57 | 2211915342.68 | 41.41 |
| PCI Girder spans 25 m (H = 160 cm) | 3644572032.00 | - | 3644572032.00 | 100.00 |
The change of bridge element design also have an impact on the value of the risk received. Application of DfMA to the bridge construction, also attempts to move most of the activities in the field into factory conditions. The risks such as weather conditions, and work safety are reduced.

5 Conclusions and recommendation

The design of bridges in Indonesia, it must meet several standard requirements. Some DfMA criteria can be used in the construction of bridge elements both in the factory environment or construction projects. There are seven precast concrete products for girder and slab bridge elements to use and further development. In the case study, one of the precast concrete products developed from the development was applied to a bridge design. The results of DfMA analysis, costs, time and risk management show that the simulation design using development products can provide efficiency better than existing designs. The construction company can cooperate with universities for research and development building components. For employment contracts, it is necessary to give more authority to specialist contractors (installation, special construction and prefabricated construction) in the system of design, engineering, procurement and implementation. Finally, the use of integral and prefabricated bridge concepts needs to be combined with DfMA for further research.

References

1. K. Min Koo, S. McGovern, M. Belsky, C. Middleton, and I. Brilakis, A Suitability Analysis of Precast Components for Standardized Bridge Construction in the United Kingdom, Proc. Eng., 164, 188-95 (2016)
2. FHWA, Accelerated Bridge Construction, TRL: https://www.fhwa.dot.gov/bridge/prefab/girder, (2018)
3. A. Aapaoja and H. Haapasalo, The Challenges of Standardization of Products and Processes in Construction, 22 983-93 (2014)
4. M. Kalyun, and T. Wodajo, Application of a Design Method for Manufacture and Assembly, Master of Science Thesis Chalmers University of Technology Sweden, (2012)
5. B. Yasin Al and A. Rjoub Al, Standardization in Construction as a Tool to Reduce Cost of Housing for the Low-Income Families in Jordan, J. of Civ. Eng. and Arch., 11, 141-148 (2017)
6. J. Zhang, Y. Long, S. Lv, and Y. Xiang. BIM-Enabled Modular and Industrialized Construction in China, Proc. Eng., 145, 1456-61 (2016)
7. M. Spišáková and M. Kozlovská. Lean Production as an Innovative Approach to Construction., J. Of Civ. Eng., 8, 87-96 (2013)
8. E. M. Generalova, V. P. Generalov, and A. A. Kuznetsova, Modular Buildings in Modern Construction. Proc. Eng. 153, 167-72 (2016)
9. Z. Yuan, C. Sun, and Y. Wang, Automation in Construction Design for Manufacture and Assembly-Oriented Parametric Design of Prefabricated Buildings, Auto. in Cons., 88, 13-22 (2018)
10. F. Pittau, L. E. Malighetti, G. Iannaccone, and G. Masera, Prefabrication as Large-Scale Efficient Strategy for the Energy Retrofit of the Housing Stock : An Italian Case Study., Proc. Eng., 180, 1160-69 (2017)
11. I. Imran, D. Hoedajanto, and I. Zarkasi, BRIDGES IN INDONESIA, JSCE Century Anniversary, (2014)
12. B. Briseghella, and T. Zordan, An Innovative Steel-Concrete Joint for Integral Abutment Bridges, J. of Traf. and Trans. Eng., 2, 209-22 (2015)
13. B. Anvari, P. Angeloudis, and W. Y. Ochieng, A Multi-Objective GA-Based Optimisation for Holistic Manufacturing, Transportation and Assembly of Precast Construction, Auto. in Const., 71, 226-41 (2016)
14. Building and Construction Authority Singapore, BIM for DJMA (Design for Manufacturing and Assembly) Essential Guide, (2016)
15. E. P. Small, K. Al Hamouri, and H. Al Hamouri, Examination of Opportunities for Integration of Lean Principles in Construction in Dubai. Proc. Eng., 196, 616-21 (2017)
16. D. T. Matt, P. Dallasega, and E. Rauch, On-Site Oriented Capacity Regulation for Fabrication...
17. R. J. Schonberger, DFMA - A Potent Lean Methodology, www.assemblymag.com, (2015).
18. S. Pulakka, S. Vares, E. Nykänen, M. Saari and T. Häkkinen, Lean Production of Cost Optimal Wooden nZEB, Energ. Proc., 96 (2016) 202-11.
19. Wijaya Karya Beton, PT. Brochure the Precast Concrete Manufacture, (2017)
20. GS E&C Corporation and Towoong E&C, BH Girder Presentation in Jakarta, (2013)
21. BSN-National Standardization Agency of Indonesia, Introduction to Standardization 2nd edition (In Bahasa), (2014).
22. Ministry of Public Work and People’s Housing Republic of Indonesia, Standardized Design of Bridge (Indonesia Language), (2015)
23. Trans Marga Jateng, PT. Contract Addendum No. 3 Contractor Services Phase II Bawen-Solo Section III : Bawen-Salatiga Package Sanjoyo River Bridge (Sta. 34+100 - Sta. 34+900), (2016)