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

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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]:

- Achievment 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].
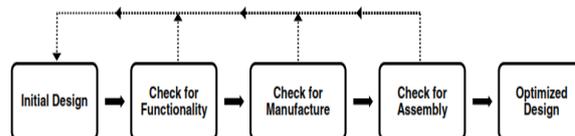

Fig. 1. DfMA procedure for a product [1]

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].
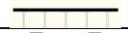
3 Research methodology

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 Indonesiain where show on Table 1.

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

DfMA criteria (8); (11)	Standarized of bridge design (10)								
	SS	D	I	M	R	E	C	A	L
Simplicity of design	✓	✓	✓	✓	✓	✓	✓	✓	✓
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

Table 2. Types, section and sizes of girder and slab bridge products [19]

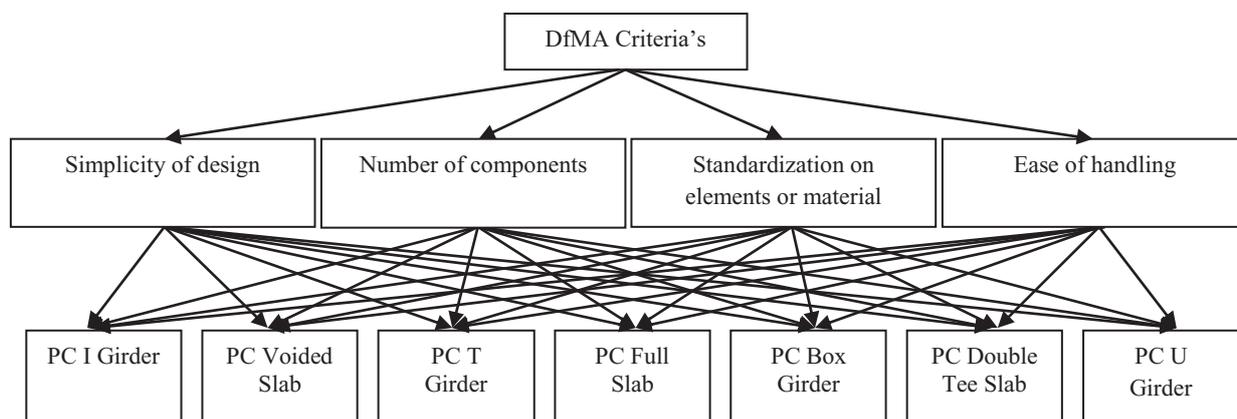| Name of product	Section	Type	Span (m)	Width (m)	Height (m)
PC Double Tee Slab		Slab	Variation	1.65 - 2.1	0, 36
PC Full Slab		Slab	Variation	Variation	Variation
PC U Girder		Girder	13 - 42	1 - 1,90	1,20 - 1,85
PC I Girder		Girder	10 - 52	0,35 - 0,8	0,9 - 2,3
PC T Girder		Girder	25 - 30	0,7 - 0,8	1.4 - 2.3
PC Voided Slab		Girder	5 - 17	0,91 – 1,2	0.57 - 0.74
PC Box Girder		Girder	20-50	8.75	2,4 - 2,5

Fig. 2. Hierarchy structure of DfMA criteria's for precast products

3.1 The assesment 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 anaythical 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	JKK	SEM	KP
SD	1.00	1.28	0.49	0.56
NC	0.78	1.00	0.31	0.52
SEM	2.05	3.27	1.00	4.08
EH	1.79	1.91	0.24	1.00
Σ	5.63	7.45	2.04	6, 17

R1 = Respondent 1; R2 = Respondent 2; R3 = Respondent 3; R4 = Respondent 4; R5 = Respondent 5; R6 = Respondent 6; R7 = Respondent 7; R8 = Respondent 8; SD = Simplicity of design; NC = Number of components; SEM = Standardization on elements or materials; EH = Ease of handling

Table 4. Normal pairwise comparison matrix

Criteria	SD	NC	SEM	EH	Weight	Average
SD	0,18	0,17	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

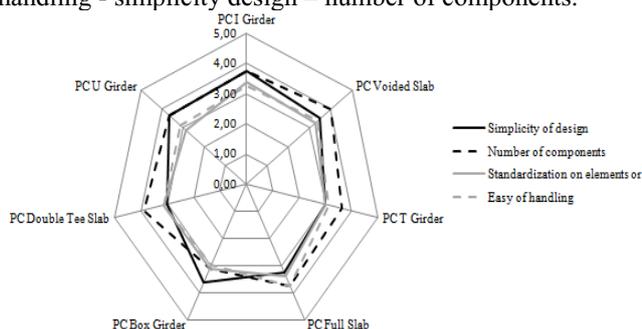standardization on elements or materials - ease of handling - simplicity design – number of components.

Fig. 3. Radar diagram

Figure 2 shows the radar diagram of the DfMA value of each product. The criteria value of each product varies between 3 to 4. Although each product has the same manufacturing location in the factory, but in design there are several parameters that must be considered. Requirements for production taken by the designer specifically are the determination of size, material requirements, transportation to the location, prestressed systems, guidelines and others. Whereas in terms of the assembly process several reasons for product selection such as conditions in the project environment, bridge span, assembly method, guidelines and so on.

Table 5. The ranking of product design

Criteria	Weight	Products												
		PC I Girder		PC Voided Slab		PC T Girder		PC Full Slab		PC Box Girder		PC Double Tee Slab		PC U Girder	
		Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
DS	0,17	3,75	0,64	3,50	0,59	3,00	0,51	3,25	0,55	3,63	0,61	3,00	0,51	3,63	0,61
JKK	0,13	3,38	0,43	3,25	0,41	3,00	0,38	3,38	0,43	3,13	0,40	3,13	0,40	2,88	0,37
SEM	0,49	3,75	1,83	4,00	1,96	3,63	1,77	3,75	1,83	3,13	1,53	3,88	1,90	3,63	1,77
KP	0,21	3,25	0,70	3,38	0,72	3,13	0,67	3,75	0,80	3,00	0,64	3,13	0,67	3,13	0,67
Total			3,60		3,69		3,33		3,62		3,18		3,47		3,42
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 revise design of 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.
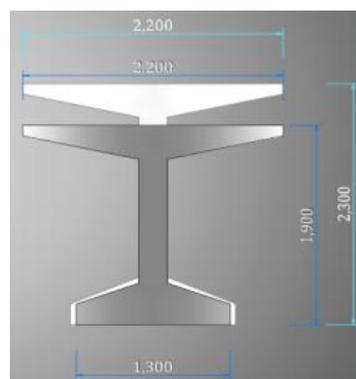

Fig. 4. Dimensions of the BH Girder [20]

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.

Table 6. Amount of elements

Elements	Material type	Symbol of Unit	Design		Difference	Efficiency (%)
			Existing	Simulation		
Bearing	Reinforced concrete	m³	4,83	12,10	(7,26)	(150)
	Fabrication of bearing	unit	90,00	60,00	30,00	33,33
	Fabrication of rubber sheet	m²	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 spandeck	m²	255,84	-	255,84	100,00
	Fabrication of deck drain	unit	78,00	68,00	10,00	12,82
	Reinforced concrete	m³	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.

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.

Table 7. Comparison of components quantity

Elements	Components	Symbol of Unit	Design		Difference	Efficiency (%)
			Existing	Simulation		
Bearing	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	m²	62.92	-	62.9 2	100.00
	Mortar and grouting	m³	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	m³	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	15390,00	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	m³	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

	Prestressed wire	unit	3216.00	7110.00	(3894.00)	(121.08)
	Live anchorage	unit	60.00	30.00	30.00	50.00
	Died end anchorage	unit	60.00	30.00	30.00	50.00
	Cables cover and accessories	unit	120.00	60.00	60,00	50,00
	Grouting	m^3	0,20	0,10	0,10	50,00
Slab	Bondeck	m^2	255,84	0,00	255,84	100,00
	Screws of bondeck	unit	1736,00	0,00	1736,00	100 , 00
	Deformed bar	kg	209270.43	244151.65	(34881.22)	(16.67)
	Deck drain	unit	78.00	68.00	10.00	12.82
	Concrete class B1	m^3	1093.68	656.21	437, 47	40.00
Expansion Joint	Seal joint	m	152.50	0.00	152.50	100.00
	Modular joint	m	47.50	105.00	(57.50)	-121.05

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.

4.2.3 Analysis ease of handling

One of the principles of DfMA is to reduce the amount of step works from the production and assembly line. 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

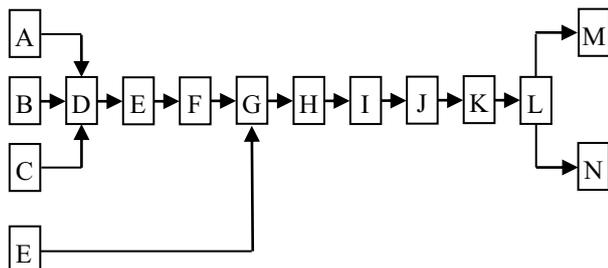ED = Existing design; SD = Simulation design

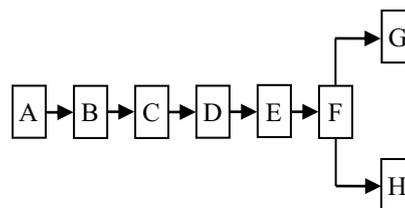**Fig. 5.** Network diagram of existing design

Fig. 6. Network diagram of simulation

In table 8 shows a list of concrete structure works between existing design and simulation design. Based on the results of analysis using a list of work details and network diagrams, it can be concluded that number of stages in simulation design is less than existing design. The efficiency that arises from this is 25%. So that with this reduction resulting in a control process in terms of handling work can be done more easily.

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. Assembliy 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					
		p	q	r	s	t	u
Existing	Crane	24	69,905	11,041	1677,731	0,158	0,164
	Gantry	36	64,805	11,041	2332,996	0,170	
Simulation	Gantry	30	64,805	11,041	1944,163	0,170	0,170

p = Amount of girder needs (units); q = Time for unit assembly girder (minutes); r = Basic assembly time of each component stage (minutes); s = Total assembly girder time (minutes) = p x q; t = DfA Index (%); u = Average value.

Table 11 is a summary of the overall duration of installation of the girder and the DfA index value in each design. All segments PC I Girder requires 4010,727 minutes, while BH Girder 1944,163 minutes means that there is 51,53% efficiency in assembly time. Based on these results it can also be seen that the amount of days time of girder installation is 10 days in the simulation design and 24 days in the existing design. The value DfA index is 0,164 % for the existing design and 0,17% for the simulation design. By looking at these conditions, it can be concluded that the simulation design has an assembly index value that is better than the existing design.

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%.
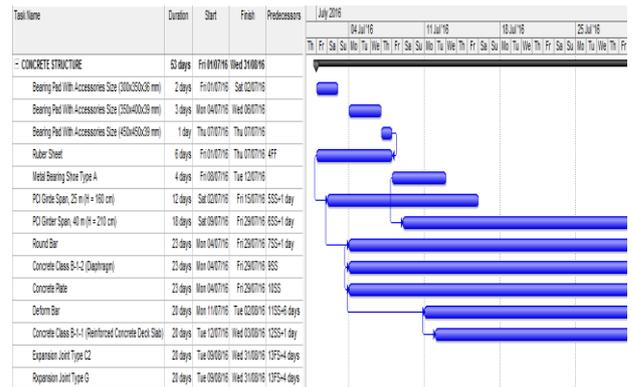

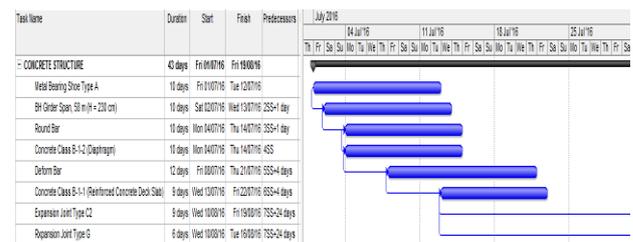
Fig. 7. Bar chart the works of existing design

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. 2215181274.21. 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 (%)
	Existing (Rp.)	Simulation (Rp.)		
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	1697492.60	4490566.25	(2793073,65)	(164,54)
Deformed bar	5340913995,25	3128998652,57	2211915342,68	41,41
PCI Girder spans 25 m (H = 160 cm)	3644572032,00	-	3644572032,00	100,00

Works	Design		Difference (Rp.)	Efficiency (%)
	Existing (Rp.)	Simulation (Rp.)		
PCI Girder spans 40 m (H = 210 cm)	11359688472,00	-	11359688472.00	100.00
BH Girder spans 58 m (H = 230 cm)	-	12789079229.79	(12789079229.79)	(100.00)
Concrete Plate	66772704,96	-	66772704.96	100.00
Expansion joint type C2	569512545,00	284756272,50	284756272,50	50,00
Expansion joint type G	535632467,50	535632467,50	-	-
Metal bearing shoe type A	143990880,00	359977200,00	(215986320.00)	(150,00)
Bearings pad size. (300x350x36 mm)	21063876.00	-	21063876.00	100.00
Bearing pad size (350x400x39 mm)	114422208.00	-	114422208.00	100.00
Bearing pad size (450x450x39 mm)	20268774.00	-	20268774.00	100.00
Ruber sheet	244680779,20	-	244680779,20	100,00
Σ	24241735772,02	18571014244,83	5670721527,19	23.39

4.2.7 Risk management

The change of bridge element design also have an impact on the value of the risk received. Application DfMA to the bridge construction, also attempts to move most of 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.

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