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Demand Analysis of Material, Construction Equipment, and Labor on the Superstructure of Type I-Girder Bridge

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ABSTRACT

Infrastructure development is one of the government's main national priority programs to support economic growth and community welfare. One of the issues encountered related to infrastructure development is that the supply chain capacity of material resources, construction equipment, and labor is not yet ideal. The purpose of this study is to analyze the demand for materials, construction equipment, and labor in the construction work of the superstructure of a type I bridge. This study used secondary data from some bridge construction work packages obtained from the Directorate General of Spatial Planning and Development, Ministry of Public Works. The research step consists of 7 stages. The total number of research samples is 32 consisting of 14 materials (x_n), 15 construction equipment (y_n), and 3 labor (z_n). Of the five bridge construction work packages, the type of materials with the largest total demand is a coarse aggregate (x_1) of 9.880,07 m^3 and a fine aggregate (x_2) of 4.049,7400 m^3. Meanwhile, the results of the construction equipment demand analysis show that the construction equipment with the longest total operational time is dump trucks (y_5) 9.395,61 hours and cranes (y_{12}) 2.849,43 hours. From the analysis of demand labor, it is known that the total working time required is workers (z_1) 250.493,970 hours, builder (z_2) 150.859,710 hours, and foreman (z_3) 59.233,110 hours. In addition, from the five construction work packages, the prestressed concrete I (PCI) girder with the longest size is 45 meters with 35 pieces, while the PCI girder with the shortest size is 20.6 meters with 14 pieces. In terms of needs, the highest number of PCI girders is 42 pieces, and PCI girders with a minimum number of 10 pieces.

1. Introduction

Indonesia is a pluralistic and the fourth most populated country in the world. According to the projections of Statistics Indonesia in 2015-2045, the population growth in 2025 will extend to 283 million people and is predicted to develop in urban areas reaching 60% of the entire population [1]. This relatively high urbanization growth must be accompanied by the availability of appropriate infrastructure.

Infrastructure is the technical, physical, hardware, and software system facilities required to provide services to society and to support structural networks that enable the improvement of economic and social development [2]. To achieve this purpose, infrastructure development is performed through infrastructure provision activities. According to the Presidential Decree of the Republic of Indonesia Number 38 of 2015 Article 5 Paragraph 2, that explained the infrastructure provision activities in Indonesia include 19 types of economic and social infrastructure. Infrastructure development is one of the main national priority programs during the administration of President Joko Widodo through the National Medium-Term Development Plan (RPJMN) [3]. The National RPJMN contains national development strategies, general policies, project priority strategic programs for Ministries/ Agencies and cross Ministry/ Agency regional and cross-regional development directions, development priorities, as well as a macroeconomic framework that includes an overall picture of the economy, comprehensive, including the direction of fiscal policy in the work plan in the form of the regulatory framework and an indicative funding framework.

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To realize the National RPJMN, the Ministry of Public Works has set the main infrastructure development target in the 2020-2024 Strategic Plan covering the fields of water resources, connectivity, and human settlements. In the connectivity, the Directorate General of Spatial Planning and Development establishes a development activities program which includes the construction of 2,500 km of toll roads, 3,000 km of new roads, 38,328 meters of a bridge, and 31,053 meters of flyover or underpass [4]. A bridge, one of the infrastructures, connects two separate places due to several conditions [5]. Structurally, a bridge is separated into two parts, namely the superstructure and the substructure [6]. The superstructure construction work consists of deck slab and pavement layers, girder, diaphragm, bracing system, bearing, and sidewalk, whereas the substructure construction work includes abutments, pillars, and foundations [7]. The construction of bridge infrastructure plays an important role in strengthening inter-regional connectivity, shortening distances between cities, helping to control the pace of development of a city, becoming a liaison to isolated areas, and supporting the better mobilization of logistics goods and services.

For the planned infrastructure development to be well conducted, it is necessary to have the support of the availability of material resources, construction equipment, and labor. However, in its implementation, issues are often found that become obstacles to infrastructure development. One of the issues encountered related to infrastructure development is that the supply chain capacity of material resources, construction equipment, and labor is not yet ideal. For example, asphalt material in 2018 was only available at 344,15 thousand tons from the actual demand of 1,872 thousand tons, while cement material in 2018 was available at around 68.13 million tons from the demand of 69.30 million tons [4].

The imbalance between supply and demand for material resources, construction equipment, and labor in Indonesia can affect the meeting of the demand concerning infrastructure development. The purpose of this study is to analyze the demand for material resources, construction equipment, and adequate labor in the construction work of the I girder bridge structure based on the work package. This research is expected to be used as an initial guide for owners, contractors, and suppliers to provide adequate construction resources.

2. Method

This study used secondary data in the form of a bridge construction work package obtained from the Directorate General of Spatial Planning and Development, Ministry of Public Works. The secondary data was obtained or collected from existing sources [8]. The work package data used include the bill of quantity, unit price analysis, project schedule, and construction methods. The total available bridge work package data were 617 work packages from 2016 to 2019. Details of the work packages can be seen in Table 1.

Table 1. Detail of work package

Year	Number of packages
2016	86
2017	159
2018	189
2019	183

The research method was conducted in 7 stages. First, the data on construction work packages each year were classified into 5 ranges of value. This was done to determine the comparison of the number of work package data each year based on the value of work packages. Table 2 shows the value classification of the bridge construction work package.

Table 2. Classification of work package value

Package Value	Year			
	2016	2017	2018	2019
10 – 24B	42	110	135	125
25 – 49B	27	41	42	45
50 – 74B	8	6	5	9
75 – 99B	1	2	2	2
> 100B	8	-	5	2

The second was determining the range of work package values observed. The selected value range of the work packages was 50B to >100B to determine the demand for material resources, construction equipment, and adequate labor in large-value bridge construction projects. The third was sorting the work package data based on the type of construction material used in the superstructure of the bridge. The superstructure of the bridge is part of the bridge structure that functions to directly carry the traffic load and distribute it to the sub-structure of the bridge [9]. Based on the construction material, the superstructure of the bridge consists of a wooden bridge, reinforced and prestressed concrete, steel, and composite bridge [10]. The focus of this research was the work of the superstructure of the bridge with reinforced concrete and prestressed construction materials.

The fourth stage was checking the document completion of the work observed. The work package must have the following documents, i.e. bill of quantity, unit price analysis, project schedule, and construction methods. Based on the description of the research method from the first to the fourth stage, 5 packages of construction work on the bridge structure with concrete construction materials were obtained which are listed in Table 3.

Table 3. Work package data

Nr.	Year	Name of Work Package	Location	Length (m)	Width (m)	Total Package Value (Rp)
1	2016	Bridge A Construction	Bengkulu Prov.	210	11,2	63.137.768.000,00
2	2016	Bridge B Construction	NTB Prov.	160	7	84.600.000.000,00
3	2016	Bridge C Construction	Maluku Prov.	323	9,8	112.100.200.000,00
4	2017	Bridge D Construction	Gorontalo Prov.	212,6	11,6	62.455.171.0000,00
5	2017	Bridge E Construction	Gorontalo Prov.	244,8	13	58.173.416.000,00

Fifth was determining the division of work observed. Physical work activities at the Directorate General of Spatial Planning and Development related to the scope of work of Connectivity generally follow the technical specifications for work contract documents; they are general specifications and special specifications [11]. Both specifications serve as the basis for compiling the unit price analysis. The general specifications for road and bridge construction in 2010 applied to the Directorate General of Spatial Planning and Development consist of 10 Divisions. Table 4 shows the general specifications of road and bridge construction works. The general specifications observed were division 6 (asphalt pavement) and division 7 (structural works), whereas the special specifications for bridges were not observed.

Table 4. General specification of road and bridge

Division	Description
1	General
2	Drainage
3	Earthwork
4	Pavement and road shoulder widening
5	Grain pavement and cement concrete pavement
6	Asphalt pavement
7	Structure
8	Return of conditions and minor work
9	Daily work
10	Routine maintenance work

In the five bridge work packages, the 6th division construction work consists of binder impregnation layer work – liquid asphalt, adhesive layer – liquid asphalt, asphalt concrete - wearing course (AC-WC), asphalt concrete - blinder course (AC-BC), asphalt concrete – Base (AC-Base), and anti-strip agents. In the 7th division, the structural work consists of 2 parts, namely the upper structure and the lower structure. Based on the type of superstructure, bridges can be divided into several types, i.e. slab bridges, voided slab bridges, girder bridges, and truss bridges [7]. The scope of work for the 7th division on the bridge superstructure with concrete construction materials consists of concrete deck slab, provision and installation of PCI girder units, prestressed concrete for diaphragms, and reinforcing steel work.

The sixth stage was determining the research sample. A sample is part of the population taken to be the object of direct observation and used as the basis for drawing conclusions [12]. This study used macro samples of materials, construction equipment, and labor. The research samples can be seen in Table 5.

The seventh stage was calculating the demand for materials, construction equipment, and labor. Analysis of material demand is the amount of material needed to complete the work in a single work unit. In calculating the material demand for the construction work of the bridge superstructure, the following equation (1) was used:

$$Material\ demand = material\ coef. \times\ work\ vol. \qquad (1)$$

In calculating the demand for construction equipment for the work of the superstructure of the bridge, equation (2) below was used:

$$Equipment\ demand = equipment\ coef. \times\ work\ vol. \qquad (2)$$

Analysis of labor demand on the work of the superstructure of the bridge was calculated using equation (3):

$$Labor\ demand = labor\ coef.\ \times\ work\ vol. \qquad (3)$$

Table 5. Material resources, construction equipment, and adequate labor sample

Sample	Definition	Unit
x_1	Coarse aggregate	m^3
x_2	Fine aggregate	m^3
x_3	Cement	Kg
x_4	Concrete sand	m^3
x_5	Asphalt	Kg
x_6	Kerosene	liter
x_7	Anti-strip agents	liter
x_8	Scaffolding wood	m^3
x_9	Concrete diaphragm	m^3
x_{10}	Plain rebar grade 24	Kg
x_{11}	Plain rebar grade 32	Kg
x_{12}	Threaded rebar grade 32	Kg
x_{13}	Threaded rebar grade 39	Kg
x_{14}	PCI girder	piece
y_1	Compressor	hour
y_2	Wheel loader	hour
y_3	AMP	hour
y_4	Generator set	hour
y_5	Dump truck	hour
y_6	Asphalt finisher	hour
y_7	Tandem roller	hour
y_8	P. tyred roller	hour
y_9	Concrete mixing plant	hour
y_{10}	Truck mixer	hour
y_{11}	Concrete vibrator	hour
y_{12}	Crane	hour
y_{13}	Trailer tronton	hour
y_{14}	Batching plant	hour
y_{15}	Concrete pump	hour
z_1	Worker	hour
z_2	Builder	hour
z_3	Foreman	hour

Description: x_n: material, y_n: construction equipment, and z_n: labor

3. Result

The total number of samples used was 32. They consisted of 14 materials (x_n), 15 construction equipment (y_n), and 3 labor (z_n). The calculation of demand for material resources, construction equipment, and labor is carried out under division 6 (asphalt pavement) and division 7 (upper structure) on the five bridge work packages. For instance, the calculation of demand for material resources, construction equipment, and labor is in the construction of bridge D located in Gorontalo province as follows:

A. Material resources

1. Division 6 (asphalt pavement)
    a. Binder impregnation layer – liquid asphalt
    Work volume: 297,50 liters
    Material demand:
    - Asphalt = 0,679 x 297,50 = 202,0025 kg
    - Kerosene = 0.3708 x 297,50 = 110,313 liters

    b. Adhesive layer – liquid asphalt
    Work volume: 105 liters
    Material demand:
    - Asphalt = 0,8487 x 105 = 89,1135 kg
    - Kerosene = 0,2068 x 105 = 21,83 liters

    c. Asphalt concrete-wearing course (AC-WC)
    Work volume: 32,34 tons
    Material demand:
    - Coarse aggregate = 0,2978 x 32,34 = 9,6309 m3
    - Fine aggregate = 0,3523 x 32,34 = 11,3934 m3
    - Cement = 9,8700 x 32,34 = 319,1958 kg
    - Asphalt = 63,8300 x 32,34 = 2.031,9222 kg

    d. Asphalt concrete – blinder course (AC-BC)
    Work volume: 48,72 tons
    Material demand:
    - Coarse aggregate = 0,3427 x 48,72 = 16,696 m3
    - Fine aggregate = 0,3127 x 48,72 = 15,235 m3
    - Cement = 9,4500 x 48,72 = 460,4040 kg

- Asphalt = 61,8000 x 48,72 = 3.010,8960 kg

e. Asphalt concrete base (AC-Base)
   Work volume: 64,68 tons
   Material demand:
   - Coarse aggregate = 0,4216 x 64,68 = 27,2691 m3
   - Fine aggregate = 0,2416 x 64,68 = 15,6267 m3
   - Cement = 9,9750 x 64,68 = 645,1830 kg
   - Asphalt = 60,7700 x 64,68 = 3.930,6036 kg

f. Anti-strip agents
   Work volume: 18,58 kg
   Material demand:
   - Anti-strip agents = 1,1 x 18,58 = 20,428 kg

2. Divison 7 (upper structure)
   a. Concrete RC plate
      Work volume: 116,13 m3
      Material demand:
      - Cement = 469,68 x 116,13 = 54.543,9384 kg
      - Concrete sand = 0,5145 x 116,13 = 59,7489 m3
      - Coarse aggregate = 0,4464 x 116,13 = 51,840 m3
      - Fine aggregate = 0,32976 x 116,13 = 34,5603 m3
      - Scaffolding wood = 0,0750 x 116,13 = 8,710 m3
   b. Concrete deck slab
      Work volume: 950,58 m3
      Material demand:
      - Cement = 469,68 x 950,58 = 54.543,9384 kg
      - Concrete sand = 0,5145 x 950,58 = 59,7489 m3
      - Coarse aggregate = 0,4464 x 950,58 = 51,840 m3
      - Fine aggregate = 0,2976 x 950,58 = 34,5603 m3
      - Scaffolding wood = 0,3000 x 950,58 = 8,710 m3
   c. Provision of PCI girder units – span 40,8 meters
      Work volume: 28 pieces
      Material demand:
      - PCI girder span 40,8 meters = 1 x 28 = 28 pieces
   d. Provision of PCI girder units – span 20,6 meters
      Work volume: 14 pieces
      Material demand:
      - PCI girder span 20,6 meters = 1 x 14 = 14 pieces
   e. Threaded rebar grade 39
      Work volume: 734.940,0200 kg
      Material demand:
      - Threaded rebar grade 39 = 1,05 x 734.940,02 = 771.687,021 kg
   f. Concrete diaphragm
      Work volume: 93,43 m3
      Material demand:
      - Concrete diaphragm = 1 x 93,43 = 93,43 m3

Based on the calculation of material demand above, 11 types of construction materials were obtained for the construction of bridge D. The recapitulation of the demand for material resources is shown in Table 6.

Table 6. Material demand on the bridge D

Sample	Description	Unit	Material demand
x_1	Coarse aggregate	m^3	529,7756
x_2	Fine aggregate	m^3	359,7077
x_3	Cement	Kg	502.437,1356
x_4	Concrete sand	m^3	548,8223
x_5	Asphalt	Kg	9.264,5378
x_6	Kerosene	liter	131,9430
x_7	Anti-strip agents	Kg	20,4380
x_8	Scaffolding wood	m^3	293,8838
x_9	Concrete diaphragm	m^3	93,43000
x_{13}	Threaded rebar 39	Kg	771.687,021
x_{15}	PCI girder span 40,8	piece	28
x_{15}	PCI girder span 20,6	piece	14

B. Construction Equipment

1. Division 6 (asphalt pavement)
   a. Binder impregnation layer – liquid asphalt
      Work volume: 297,50 liters
      Equipment demand:
      - Compressor = 0,0042 x 297,50 = 1,250 hours
      - Dump truck = 0,0042 x 297,50 = 1,250 hours
   b. Adhesive layer – liquid asphalt
      Work volume: 105 liters
      Equipment demand:
      - Compressor = 0,0042 x 105 = 0,4410 hours
      - Dump truck = 0,0042 x 105 = 0,4410 hours
   c. Asphalt concrete-wearing course (AC-WC)
      Work volume: 32,34 tons
      Equipment demand:
      - Wheel loader = 0,0491 x 32,34 = 1,5879 hours
      - AMP = 0,0500 x 32,34 = 1,6170 hours
      - Generator set = 0,0500 x 32,34 = 1,6170 hours
      - Dumpt truck = 0,1666 x 32,34 = 5,3878 hours
      - Asphalt finisher = 0,0529 x 32,34 = 1,7108 hours
      - Tandem roller = 0,0463 x 32,34 = 1,4973 hours
      - P. tyred roller = 0,0483 x 32,34 = 1,5620 hours
   d. Asphalt concrete – blinder course (AC-BC)
      Work volume: 48,72 tons
      Equipment demand:
      - Wheel loader = 0,0469 x 48,72 = 2,2850 hours
      - AMP = 0,0500 x 48,72 = 2,4360 hours
      - Generator set = 0,0500 x 48,72 = 2,4360 hours
      - Dumpt truck = 0,1666 x 48,72 = 8,1168 hours
      - Asphalt finisher = 0,0127 x 48,72 = 0,6187 hours
      - Tandem roller = 0,0237 x 48,72 = 1,1547 hours
      - P. tyred roller = 0,0177 x 48,72 = 0,8623 hours
   e. Asphalt concrete base (AC-Base)
      Work volume: 64,68 tons
      Equipment demand:
      - Wheel loader = 0,0480 x 64,68 = 3,1046 hours
      - AMP = 0,0500 x 64,68 = 3,2340 hours
      - Generator set = 0,0500 x 64,68 = 3,2340 hours

- Dumpt truck = 0,1666 x 64,68 = 10,7757 hours
- Asphalt finisher = 0,0126 x 64,68 = 0,8150 hours
- Tandem roller = 0,0124 x 64,68 = 0,8020 hours
- P. tyred roller = 0,0071 x 64,68 = 0,4592 hours

2. Divison 7 (upper structure)
   a. Concrete RC plate
      Work volume: 116,13 m3
      Equipment demand:
      - Batching plant = 0,1666 x 116,13 = 19,350 hours
      - Truck mixer = 0,5055 x 116,13 = 58,7037 hours
      - Concrete vibrator = 0,333 x 116,13 = 38,71 hours
   b. Concrete deck slab
      Work volume: 950,58 m3
      Equipment demand:
      - Batching plant = 0,1666 x 950,58 = 158,37 hours
      - Truck Mixer = 0,5055 x 950,58 = 480,5182 hours
      - Concrete pump = 0,1666 x 950,58 = 158,4 hours
      - Concrete vibrator = 0,333 x 950,58 =316,5 hours
   c. Provision of PCI girder units – span 40,8 meters
      Work volume: 28 pieces
      Equipment demand:
      - Crane = 7,2289 x 28 = 202,4092 hours
   d. Installation of PCI girder units – span 40,8 meters
      Work volume: 28 pieces
      Equipment demand:
      - Crane = 9,0666 x 28 = 253,8648 hours
   e. Provision of PCI girder units – span 20,6 meters
      Work volume: 14 pieces
      Equipment demand:
      - Crane = 3,5435 x 14 = 49,6090 hours
   f. Installation of PCI girder units – span 20,6 meters
      Equipment demand:
      - Crane = 7,3230 x 14 = 102,5220 hours
   g. Concrete diaphragm
      Work volume: 93,43 m3
      Equipment demand:
      - Crane = 0,8928 x 93,43 = 83,4143 hours

From the calculation results, it is obtained 13 types of construction equipment in the construction of bridge D. Table 7 shows the type and total operational time required for the construction equipment in the construction of bridge D.

C. Labor

1. Division 6 (asphalt pavement)
   a. Binder impregnation layer – liquid asphalt
      Work volume: 297,50 liters
      Labor demand:
      - Worker = 0,0425 x 297,50 = 12,6438 hours
      - Builder = 0,0042 x 297,50 = 1,250 hours
      - Foreman = 0,0042 x 297,50 = 1,250 hours

Table 7. Construction equipment demand on the bridge D

Sample	Description	Unit	Equipment demand
y_1	Compressor	hour	1,6905
y_2	Wheel loader	hour	6,9775
y_3	AMP	hour	7,2870
y_4	Generator set	hour	7,2870
y_5	Dump truck	hour	25,9708
y_6	Asphalt finisher	hour	3,1445
y_7	Tandem roller	hour	3,4540
y_8	P. tyred roller	hour	2,8836
y_{10}	Truck mixer	hour	539,2219
y_{11}	Concrete vibrator	hour	355,2493
y_{12}	Crane	hour	785,3663
y_{14}	Batching plant	hour	177,7139
y_{15}	Concrete pump	hour	158,3666

   b. Adhesive layer – liquid asphalt
      Work volume: 105 liters
      Labor demand:
      - Worker = 0,0425 x 105 = 4,4625 hours
      - Builder = 0,0042 x 105 = 0,4410 hours
      - Foreman = 0,0042 x 105 = 0,4410 hours
   c. Asphalt concrete-wearing course (AC-WC)
      Work volume: 32,34 tons
      Labor demand:
      - Worker = 1,0000 x 32,34 = 32,340 hours
      - Foreman = 0,1000 x 32,34 = 3,2340 hours
   d. Asphalt concrete – blinder course (AC-BC)
      Work volume: 48,72 tons
      Labor demand:
      - Worker = 1,0000 x 48,72 = 48,720 hours
      - Foreman = 0,1000 x 48,72 = 4,8720 hours
   e. Asphalt concrete base (AC-Base)
      Work volume: 64,68 tons
      Labor demand:
      - Worker = 0,5000 x 64,68 = 32,340 hours
      - Foreman = 0,0500 x 64,68 = 3,2340 hours

2. Divison 7 (upper structure)
   a. Concrete RC plate
      Work volume: 116,13 m3
      Labor demand:
      - Worker = 6,5000 x 116,13 = 754,8450 hours
      - Builder = 1,5000 x 116,13 = 174,1950 hours
      - Foreman = 0,1666 x 116,13 = 19,3473 hours
   b. Concrete deck slab
      Work volume: 950,58 m3
      Labor demand:
      - Worker = 5,8333 x 950,58 = 5.545,0183 hours
      - Builder = 2,5000 x 950,58 = 2.376,4500 hours
      - Foreman = 0,3333 x 950,58 = 316,8283 hours
   c. Provision of PCI girder units – span 40,8 meters
      Work volume: 28 pieces

Labor demand:
- Worker = 126 x 28 = 3.528 hours
- Builder = 35 x 28 = 980 hours
- Foreman = 7 x 28 = 196 hours

d. Installation of PCI girder units – span 40,8 meters
Work volume: 28 pieces
Labor demand:
- Worker = 126 x 28 = 3.528 hours
- Builder = 35 x 28 = 980 hours
- Foreman = 7 x 28 = 196 hours

e. Provision of PCI girder units – span 20,6 meters
Work volume: 14 pieces
Labor demand:
- Worker = 63,0000 x 14 = 882 hours
- Builder = 17,5000 x 14 = 245 hours
- Foreman = 3,5000 x 14 = 49 hours

f. Installation of PCI girder units – span 20,6 meters
Labor demand:
- Worker = 63,0000 x 14 = 882 hours
- Builder = 17,5000 x 14 = 245 hours
- Foreman = 3,5000 x 14 = 49 hours

g. Threaded rebar grade 39
Work volume: 734.940,0200 kg
Labor demand:
- Worker = 0,0437 x 734.940,02 = 32.116,8789 hours
- Builder = 0,0437 x 734.940,02 = 32.116,8789 hours
- Foreman = 0,0109 x 734.940,02 = 8.010,8462 hours

h. Concrete diaphragm
Work volume: 93,43 m3
Labor demand:
- Worker = 8,9280 x 93,43 = 834,1430 hours
- Builder = 0,8928 x 93,43 = 83,4143 hours
- Foreman = 0,8928 x 93,43 = 83,4143 hours

The calculation demand for labor on work items in division 6 dan division 7 shows the working time needed by laborers to complete the work on the structure of bridge D. The total amount of the working time requirements for the bridge construction work package D are shown in Table 8.

Table 8. Labor demand on the bridge D

Sample	Description	Unit	Labor demand
z_1	Worker	hour	48.201,3915
z_2	Builder	hour	37.202,6287
z_3	Foreman	hour	8.933,4660

Calculation of demand for material resources, construction equipment, and labor is carried out on the other four bridge work packages. The detailed result of the calculation of material resources, construction equipment, and labor parameter requirements is presented in Table 9.

The comparison of the demand for material resources, construction equipment, and labor in each work package can be seen in Figure 1 – Figure 3. Figure 1 shows the demand for each material in the five bridge work packages. To find out the comparison of the material demand, the 14 types of materials are converted into m^3. Based on Figure 1, the largest material demand used in the five bridge work packages was Coarse aggregate (x_1) with a total amount of 9.880,07 m^3. The second largest material demand was Fine aggregate (x_2) with 4.049,7400 m^3. The minimum material demand was anti-strip agents of 2,3500 m^3.

Figure 2 shows the calculation of construction equipment demand used in the five bridge work packages. From Figure 2, it is known that the most extensively used was the dump truck (y_5) with 9.395,61 hours of the total operational period. The second most used construction equipment was a crane (y_{12}) with 2.849,43 hours.

Analysis of labor demand showed the duration of a worker (z_1), a builder (z_2), and a foreman (z_3) to finish the superstructure of the bridges in the five work packages was varied (Figure 3). The total working hour needed for a worker (z_1) was 250.493,970 hours, a builder (z_2) was 150.859,710 hours, and a foreman (z_3) was 59.233,110 hours.

Table 9. Result of calculation of material, construction equipment, and labor requirement

Sample	Unit	Package A	Package B	Package C	Package D	Package E
x_1	m^3	3.038,99	3.005,21	2.640,54	529,78	665,55
x_2	m^3	2.294,72	453,43	490,99	359,71	450,89
x_3	m^3	356,35	1.300,57	954,97	349,45	449,54
x_4	m^3	426,86	1.622,34	1.496,77	548,82	706,46
x_5	m^3	343,83	4,36	84,30	7,15	7,15
x_6	m^3	4,43	2,67	0,61	0,13	0,13
x_7	m^3	1,62	0,37	0,31	0,03	0,02
x_8	m^3	326,03	1.091,86	1.202,97	293,88	383,48
x_9	m^3	9,30	14,30	100,25	93,43	98,15
x_{10}	m^3	19,89	1,28	4,22	-	-
x_{11}	m^3	7,22	-	-	-	-
x_{12}	m^3	30,51	-	-	-	-
x_{13}	m^3	-	72,54	53,24	98,30	80,91
x_{14}	m^3	843,57	307,30	1.180,46	947,57	1.284,34
y_1	hour	2,69	3,08	24,50	1,69	1,91
y_2	hour	215,19	23,22	104,31	6,98	6,98
y_3	hour	154,92	39,63	61,84	7,29	7,29
y_4	hour	154,92	39,63	386.81	7,29	7,29
y_5	hour	4.526,30	4.649,53	167,84	25,97	25,97
y_6	hour	177,26	22,24	18,21	3,14	3,14
y_7	hour	231,98	20,34	19,66	3,45	3,45
y_8	hour	277,03	4,724	8,76	2,88	2,88
y_9	hour	75,26	-	-	-	-
y_{10}	hour	334,48	-	-	-	694,10
y_{11}	hour	245,51	-	-	355,25	45,28
y_{12}	hour	213,87	1.009,18	13,69	691,8193	920,87
y_{13}	hour	0,38	-	13,49	-	-
y_{14}	hour	-	440.2775	120,90	177,71	228,76
y_{15}	hour	-	155,85	120,90	158,37	207,69
z_1	hour	32.728,43	79.665,31	41.133,82	48.201,3915	48.765,02
z_2	hour	21.559,90	43.721,05	14.871,30	37.202,6287	33.504,83
z_3	hour	7.479,15	27.870,67	7.084,16	8.933,4666	7.865,66

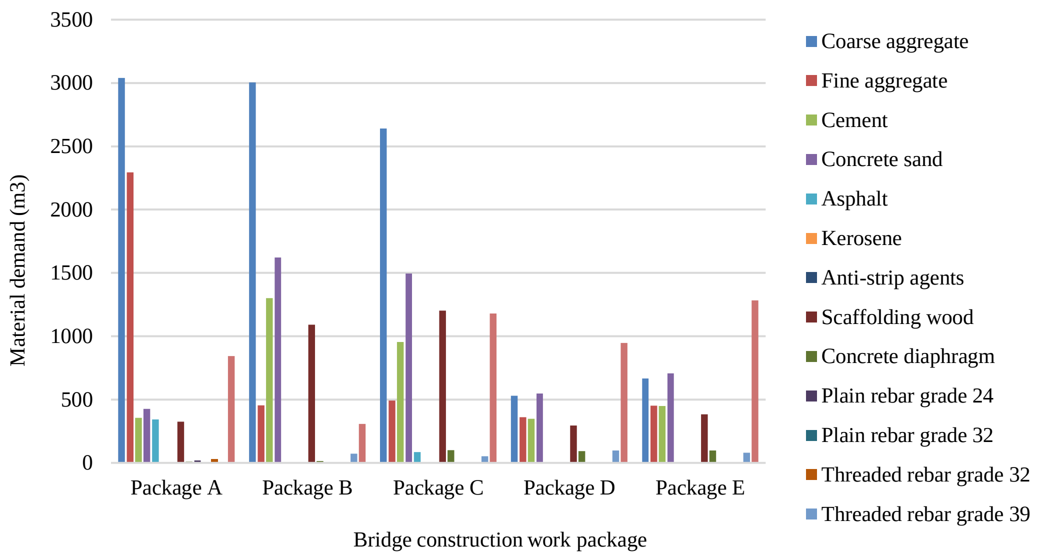

Figure 1. Comparison of the material demand for the five bridge work packages

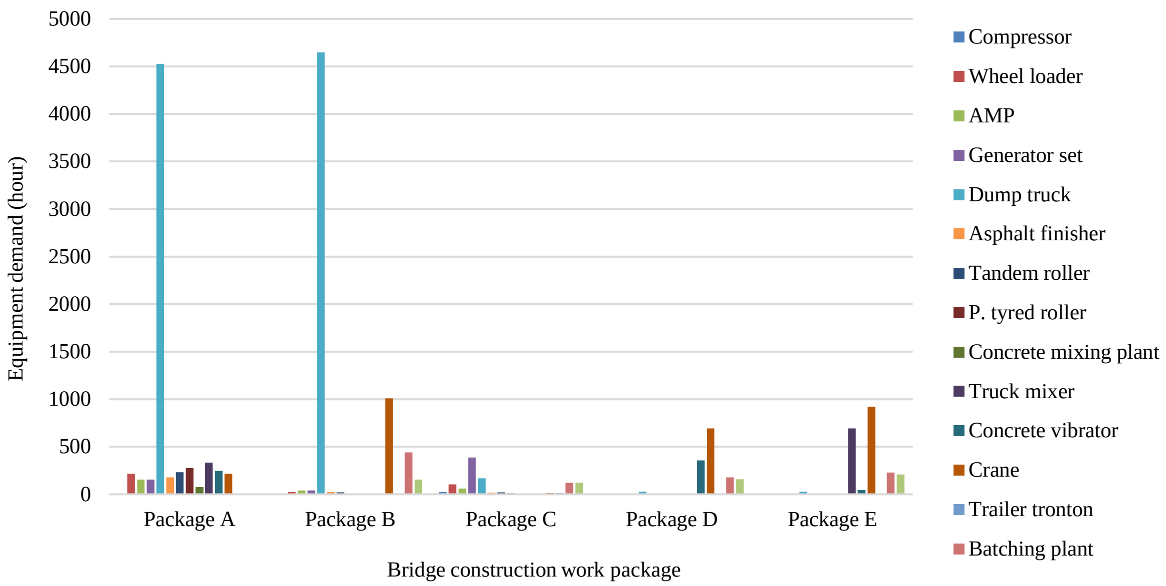

Figure 2. Comparison of the construction equipment demand for the five bridge work packages

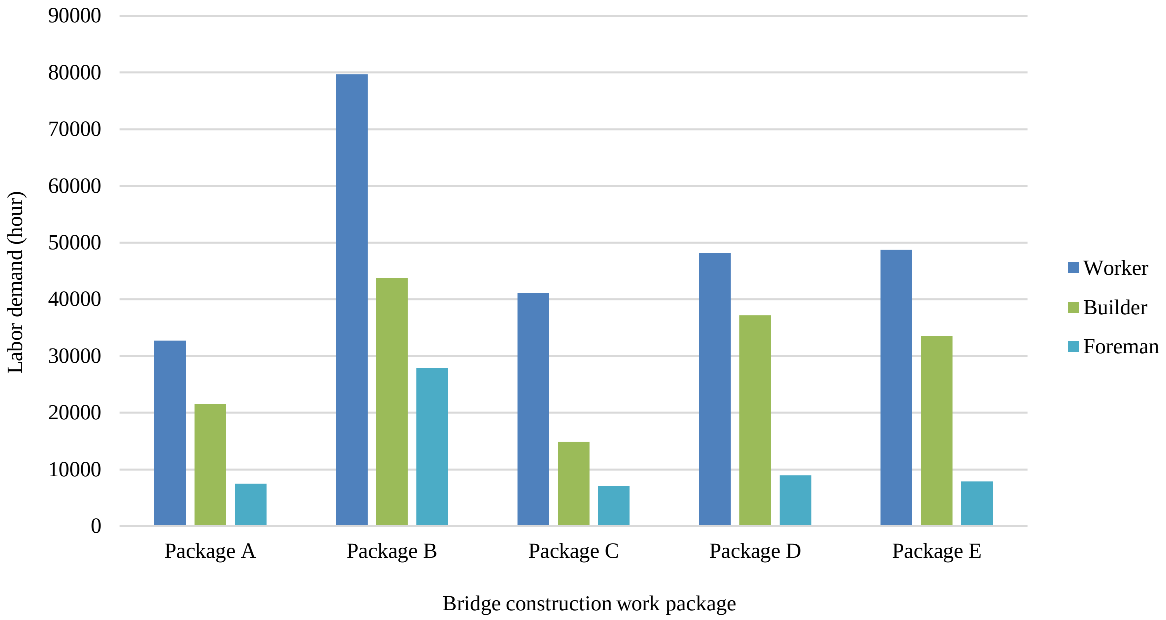

Figure 3. Comparison of the labor demand for the five bridge work packages

In addition to calculating the demand for material, construction equipment, and labor, identification of the type of superstructure used in the bridge work package was also performed. From the five construction work packages, the type of bridge superstructure used was the girder. The girder is a part of the upper structure that functions to distribute the load in the form of traffic loads, self-weight of the girder, and other loads above the girder to the lower part of the structure [13]. Generally, the girder is a steel beam with an I profile but can be in the form of a box or other shapes [14]. The form of girder used in the five work packages was a type I precast girder or prestressed concrete I girder (PCI girder). Precast girders are concrete girders that have been molded at the factory and then brought to the bridge construction work site for installation (7). The length of the girder span and the number of PCI girder requirements for each work package were different. Table 10 shows the length and PCI girder requirements for each bridge.

Table 10. Length and PCI girder demand

Nr.	Work Package	PCI *girder* (unit) demand				
		20,6m	35m	40,8m	41m	45m
1	Bridge A Construction		36			
2	Bridge B Construction				10	
3	Bridge C Construction					35
4	Bridge D Construction	14		28		
5	Bridge E Construction			42		

Based on Table 10, the construction of bridge C located in Maluku Province used PCI girders with the longest size of 45 meters with 35 units, whereas PCI girders with the shortest size of 20,6 meters with 14 pieces were applied to the construction of bridge D in Gorontalo Province. Looking at the requirements, the construction of bridge D and bridge E required the highest number of PCI girders, which was 42 pieces, while the construction of bridge B in NTB Province required PCI girders with a minimum number of 10 pieces.

This study aimed to provide an overview to owners, contractors, and suppliers regarding the demand for materials, construction equipment, and labor on bridge construction projects in Indonesia. The calculation results showing the differences in material, construction equipment, and labor demands on the superstructure of each bridge could be influenced by the dimensions of the bridge, the bridge class, the location of the bridge construction, and the year of the construction work package.

4. Conclusion

Based on the results of this study, the demand for 32 samples on the work of the bridge superstructure is obtained. The type of material that has the largest total demand of the five work packages is a coarse aggregate (x_1) of 9.880,07 m^3 and a fine aggregate (x_2) of 4.049,7400 m^3. The two highest material demands in the construction of bridge A in Bengkulu Province with a coarse aggregate of 3.038,99 m^3 and a fine aggregate of 2.294,72 m^3, whereas the lowest material demands in the construction of bridge D in Gorontalo Province with a coarse aggregate of 529,78 m^3 and a fine aggregate of 359,71 m^3. In addition, the type of material that has the minimum total demand of the five work packages is anti-strip agents of 2,3500 m^3. This material is at least used in the construction of bridge E in Gorontalo Province of 0,0248 m^3. The results of the calculation of the demand for construction equipment show that the types of construction equipment that require the longest total operational time of the five bridge work packages are dump trucks (y_5) for 9.395,61 hours and cranes (y_{12}) for 2.849,43 hours. Two construction equipment operate the longest in the construction of bridge B with a dump truck operating time of 4.649,53 hours and a crane for 1.009,18 hours. From the analysis of labor demand, the construction of bridge B is a work package that requires labor with the longest working time compared to the other four bridge work packages. The amount of working time needed by laborers to complete the work on the structure of the bridge B is workers (z_1) with 79,665.31 hours, builder (z_2) with 43,721.05 hours, and foreman (z_3) with 27,870.67 hours. Furthermore, from the five work packages, it is known that the PCI girder with the longest size is 45 meters, while the PCI girder with the shortest size is 20,6 meters. Looking at the requirements, the PCI girders with the highest number reach 42 pieces and the PCI girders with the least number are 10 pieces. This research is expected to be used as an academic study regarding the calculation of demand for material resources, construction equipment, and labor in the construction sector. Moreover, this research also provides an overview of the types of materials, construction equipment, and labor that have a large total demand for the construction of the superstructure of the type I-girder bridge.

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