Automation in Construction 20 (2011) 837–863

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Modularization and assembly algorithm for efficient MEP construction

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ARTICLE INFO

Article history:
Accepted 1 March 2011
Available online 21 April 2011

Keywords:
MEP system
Prefabrication
Schedule delay
Space conflict

ABSTRACT

This paper presents an algorithm for efficiently designing, fabricating, and constructing the mechanical, electrical, and plumbing (MEP) systems for buildings. MEP facility construction presents numerous challenges related to its complexity, space limitations, and interference with other trades working in confined areas. Besides, schedule delays can easily be caused by the uncontrolled delivery schedule of the components. This research provides a rational planning algorithm which packages large and complex MEP systems into several smaller fabricated components using spatial planning algorithms to increase the efficiency of the installation process, create a safer work environment, improve construction quality and productivity, reduce construction cycle time, and minimize cost. Furthermore, the technique is verified and validated by three experts and a case study is presented to demonstrate the effectiveness of this algorithm.

1. Introduction

Mechanical, electrical and plumbing (MEP) systems represent a substantial portion of commercial and industrial projects, where in some cases, they represent 25%–40% of the total project cost [8]. MEP systems directly impact the safety, operating efficiency and energy utilization, and flexibility of the structural and architectural design [7]. Given the importance of the MEP portion of a facility, this research investigates how to efficiently layout and assemble piping systems in the mechanical rooms. Considerations include more efficient distribution of labor, equipment, and materials.

Construction of MEP rooms usually has two major limiting factors, space limitations and schedule delays. These factors typically cause safety issues, space conflicts between subcontractors, delays in piping installation, poor workmanship, and ultimately increased costs.

Space limitations relate to narrow and confined work spaces which make it more difficult to introduce large and heavy pieces of equipment as well as the labor necessary for assembly and installation. Pipes must either be hoisted or installed on the floor of the MEP room and may require complicated pipe supports. Supports installed in these confined rooms create path interference and make installation awkward for pipe fitters. In addition, limited space also causes the cost increasing. When worker weld the pipe too close to the wall, ceiling, floor or other pipes in the room, they have to use some special method to weld instead of the general method, and the special method is more expensive.

Moreover, when worker weld pipes in a small MEP room in the basement, the ventilation is worse and the toxic gasses generated when they weld would cause them poisoning.

Delays are primarily related with the sometimes uncontrollable delivery of fabricated pipe spools and the equipments. This is particularly true in Taiwan and other developing nations where production techniques are maturing and purchases need to be made from manufacturers in other countries. Thus, the delivery time is difficult to control and can influence the construction schedule.

Furthermore, as a customary practice, the pipe in the MEP room is usually installed after many of the other components are in place (walls, electrical conduit, etc.) This is due to concerns that the final facility size

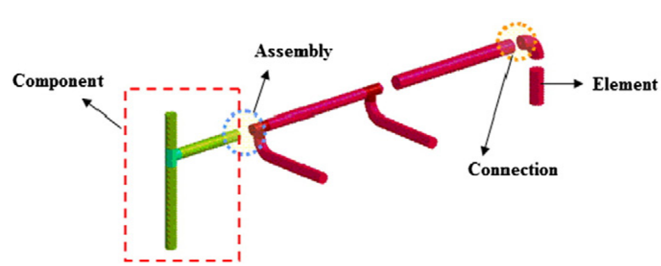

Fig. 1. Basic definitions.

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E-mail addresses: hptserng@ntu.edu.tw (H.P. Tserng), Samuel@mail.ruentex.com.tw (Y.L. Yin), ejaselsk@iastate.edu (E.J. Jaselskis), D95521011@ntu.edu.tw (W.-C. Hung), RT007174@mail.ruentex.com.tw (Y.-C. Lin).

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doi:10.1016/j.autcon.2011.03.002

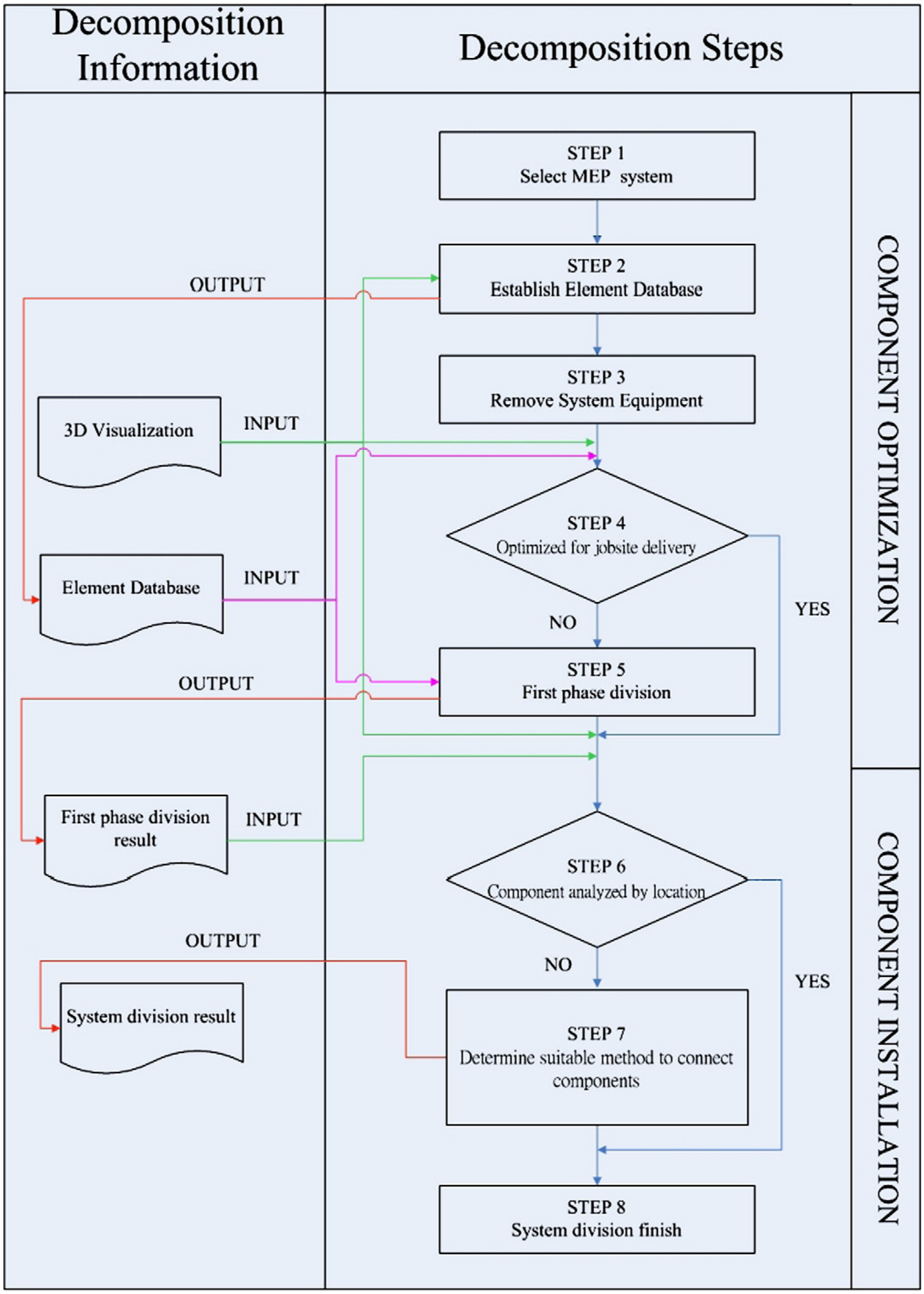


Fig. 2. Basic framework for the methodology.

may be different from the original design and equipment locations will be different than originally planned. Delaying the timing of piping installation can increase both time and cost of the project.

Due to the numerous complexities associated with designing and constructing MEP facilities (e.g., high density of welded and flanged connections, large numbers of instruments, and varied piping systems)

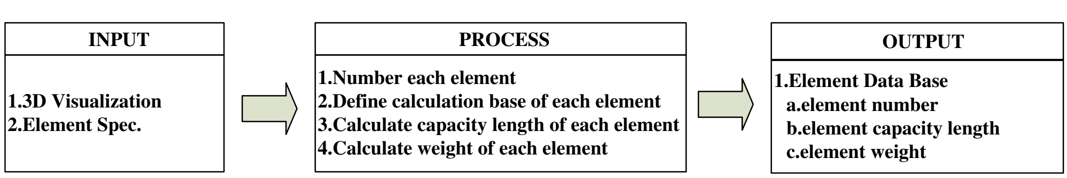
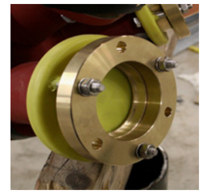
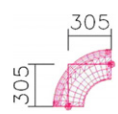
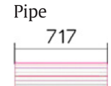
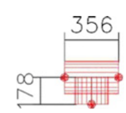
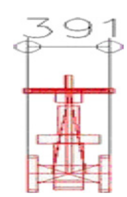
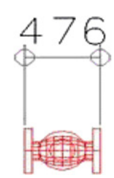
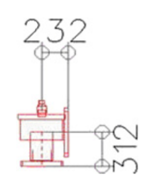
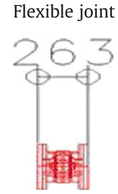
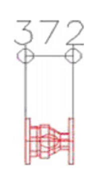
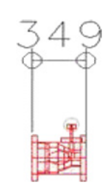


Fig. 3. Flowchart of establishing database of elements.

Table 1
Element table.

Element	Description	Diagram		
Flanges and shims	The slip-on flange is adopted for this study.			
Gaskets	Since the thickness of the gasket does not influence pipe prefabrication, rubber gasket is not considered in the procedure of system division.			
Mechanical joint	Mechanical joints are considered for this research study since they are more flexible and easier to install compared to the screw-type joints.			
Pipe and Fittings	The division of pipe materials and fittings is calculated by counting the length from the pipe center to the end.	Elbow 	Pipe 	Tee 
Valves	The division of valves is calculated by determining the distance between the horizontal or vertical inlet and outlet.	Gate valve 	Swing check valve 	Pressure relief valve 
		Flexible joint 	Reducer 	Flow meter 

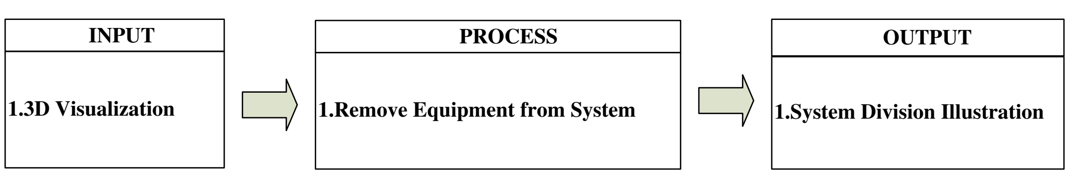


Fig. 4. Remove system equipment.

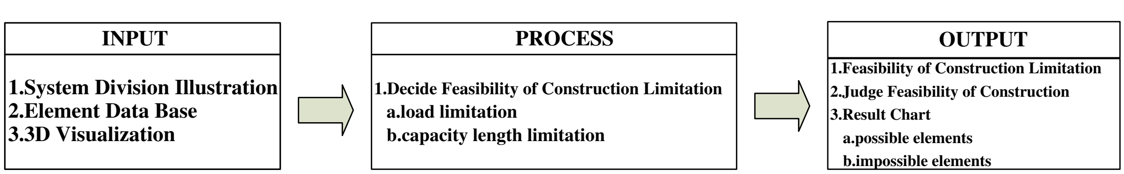


Fig. 5. Component optimization for jobsite delivery.

Table 2
Transportation/Temporary hoist equipments.

Transportation equipment		Temporary hoist equipment
Handcart	Handcart	Chain block
		

The load limit of the equipment is about 500 kg_f.

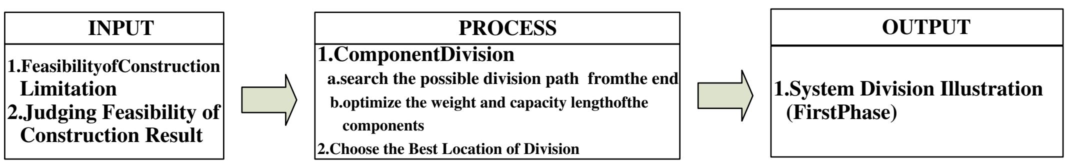


Fig. 6. First phase of system decomposition.

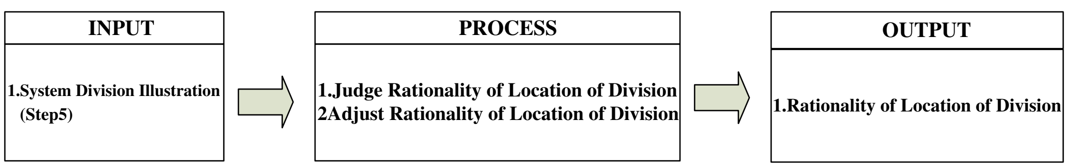


Fig. 7. Optimization for location of division.

there is a great need to help streamline the MEP piping process. This research breaks the large and complex MEP system into several manageable fabricated components using 3D graphics and novel spatial planning technique. The proposed algorithm is designed to increase construction space and worker safety, enhance construction quality, improve job efficiency; moreover, shorten construction duration and decrease cost.

A case study illustrates the practicality of applying the piping algorithm described in this paper with the following considerations:

1. 3D visualizations are made from actual as-built conditions at the site and consider the quantity, location, specification, type of facility, and special length of each pipe section.

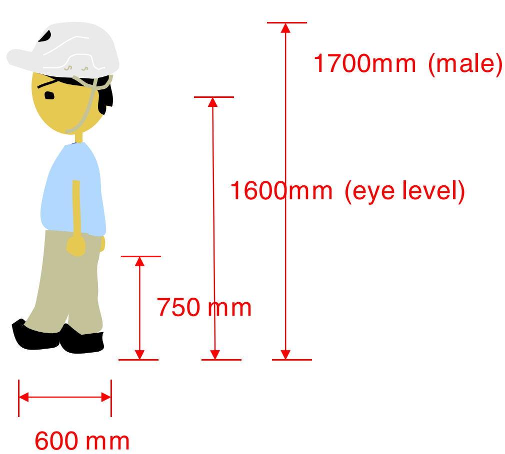


Fig. 8. Required operating space for normal construction.

2. It is physically possible to provide precise interface connections between the piping and equipment.
3. Foundations and the actual pipe hoisting process are not taken into account.

2. Related Works

There appears to be limited research on construction in confined spaces especially related to MEP facilities. Much of the past research pertains to general space management and demand. Space management research focuses primarily on space optimization, such as dynamic layout of temporary facilities using a graphical interactive interface as presented by Tommelein and Zouein [17]. Yeh [18] presented a site layout model using neural networks. Li and Love [12] solved the site layout of the temporary facilities by using genetic algorithms. Hegazy and Elbeltagi [11] used a similar approach to optimize the site layout of temporary facilities. Tommelein and Zouein [15] presented their Hybrid Incremental Solution Method, where, for each heuristically selected resource, constraint satisfaction is used to compute sets of feasible positions. Subsequently, a linear program is solved to find the optimal location for each resource so as to minimize total costs. Tommelein and Zouein [16] presented a combination of space and construction items to create a flexible space usage schedule.

Much research has been performed in the area of space demand. Thabet and Beliveau [14] defined the working space demands for high-rise building. Riley and Sanvido [13] presented models of construction space usage for multi-story buildings. The use of 4D simulation, which combines 3D space and time, is also discussed as a tool for better understanding space demand by Akinci et al. [3]. Akinci et al. [4] explored the use of visualization of the construction facility space demands using 4D simulation techniques. Site layout simulation using 4D models was

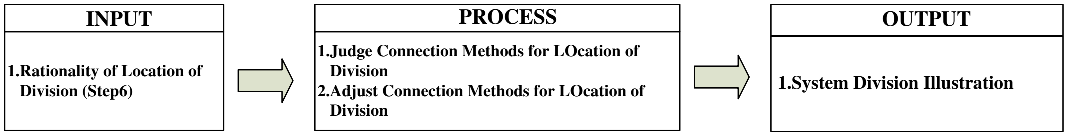


Fig. 9. Optimization for connecting methods for division.

investigated by Chau et al. [6]. Although there is considerable research on space management, most of the issues focus on the simulation of site layout.

There is minimal research on confined construction areas, such as MEP facility erection. Guo [10] revealed that congested construction spaces will cause low production capacity and possible schedule delay. The working schedule of MEP facilities is usually a critical milestone in the schedule. However, if the MEP facility requires the fabrication of several components from other countries, production and transportation alone can quite easily delay the schedule. Assaf et al. [5] discovered that the delay of special products from other countries was the fourth most significant source of delay for contractors. Majid [1] found that late delivery is the most significant source of delay. Darshi de Saram and Ahmed [9] proposed that coordinating offsite fabrication and delivery with on site work provides a modest degree of efficiency in the work integration to the schedule. Abdul-Rahman [2] presented findings that showed that about 12% of schedule delays are caused by machinery and electrical installation.

3. Framework of Research Methodology

Traditional construction method does not include both concepts of modularization and pre-fabricate. In some large projects, because of many configurations of the pipeline in mechanical, electrical, plumbing and fire suppression systems are most repetitively, the traditional construction method is less effective for the repetitive works. Thus, the basic concept of this study tries to introduce the concepts of modularization and pre-fabricate into traditional construction method.

Because the size and location of equipments may be slightly different from the design, the most important limitation of modularization is that workers cannot pre-set from the site to check the accuracy of the pipe assembly. Due to the limitation, cutting point selection and how to choose the assembled method after cutting will affect the efficiency of the pipe installation and the error absorption, and these are what this study focuses on.

The research method involves two major and several smaller steps. The major parts of the framework involve two parts: (1) component optimization for jobsite delivery and (2) component optimization for installation. Smaller routines in the model relate to breaking down the MEP system into its elemental components, removing equipment, and incorporating constraint criteria of optimal jobsite delivery and installation. Basic definitions are provided along with a framework model showing the approach in more detail.

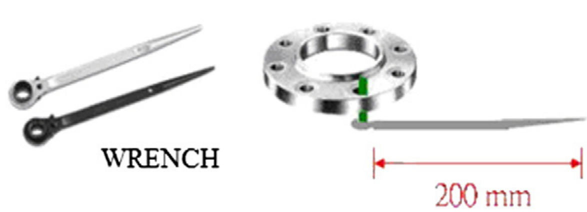


Fig. 10. Wrench for flange.

3.1. Basic Definitions

Basic definitions for terms used in the research are listed below and as shown in Fig. 1:

1. System: Includes all piping components, sensor instrumentation and equipment found in a MEP room.
2. Equipment: Includes all engineered equipment located in the MEP room such as large-sized generators, motors, compressors, condensers, and pumps.
3. Element: Smallest items in the system such as elbows, pipe sections, valves, and equipment (refer to Fig. 1).
4. Components: The combination of more than two elements through the use of welded or flanged connections. Components can be directly acquired from a fabricator (refer to Fig. 1).
5. Assembly: The combination of two or more components through the use of welded or flanged connections (refer to Fig. 1).
6. Loop: A special assembly of components that describes a closed system of piping in an MEP system such as fire suppression, chilled water for air conditioning, and hot water for heating.
7. Connection: Joint between elements in the same component (refer to Fig. 1).

3.2. Overview of Framework

The basic framework for this methodology involves the following steps and as shown in Fig. 2:

1. Analysis of component optimization for jobsite delivery
   The main purpose of this optimization is to explore the method of system division and to define the size and weight attributes of each element using 3D visualization for jobsite delivery. This is accomplished by performing the following steps:
   Step 1 Select MEP system: This is the first step in the algorithm and involves identifying the MEP system to be analyzed which could include the entire system or a subsystem (e.g., fire suppression).
   Step 2 Establish element database: Number all elements in the system and record their weight and capacity length as defined later in this paper.
   Step 3 Remove system equipment: Extract equipment from the 3D model in order to simplify the decomposition process.
   Step 4 Optimize for jobsite delivery: Judge the feasibility of construction installation by analyzing the attributes of each component such as its weight and capacity length. This includes consideration for the lifting equipment capabilities on site.

Table 3
Replaceable connection methods.

Original condition	Replaceable methods
Flange with a narrow operating space	Mechanical joint (refer to Table 1)
Welded joint with a narrow operating space	Flange joint or mechanical joint
Bent pipe or long pipe	Welded joint, flange joint, or mechanical joint

Table 4
Equipments in MEPF systems.

System	Real picture	Equipments
Mechanical system		Generator, motor, cabinet, and control power transformer
Electrical system		Generator, cabinet, and control power transformer
Plumbing system		Generator and motor
Fire suppression system		Generator, motor, and foam tank

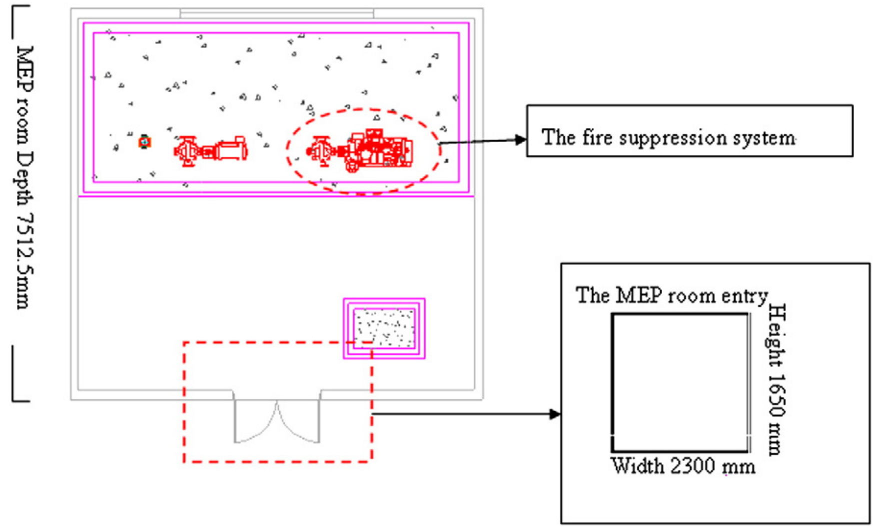


Fig. 11. The MEP room.

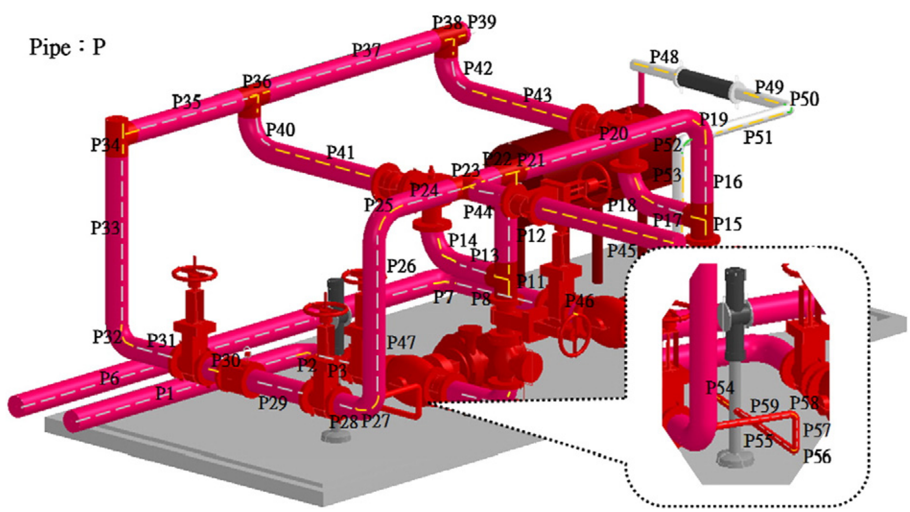


Fig. 12. Fire suppression system showing all pipe castings.

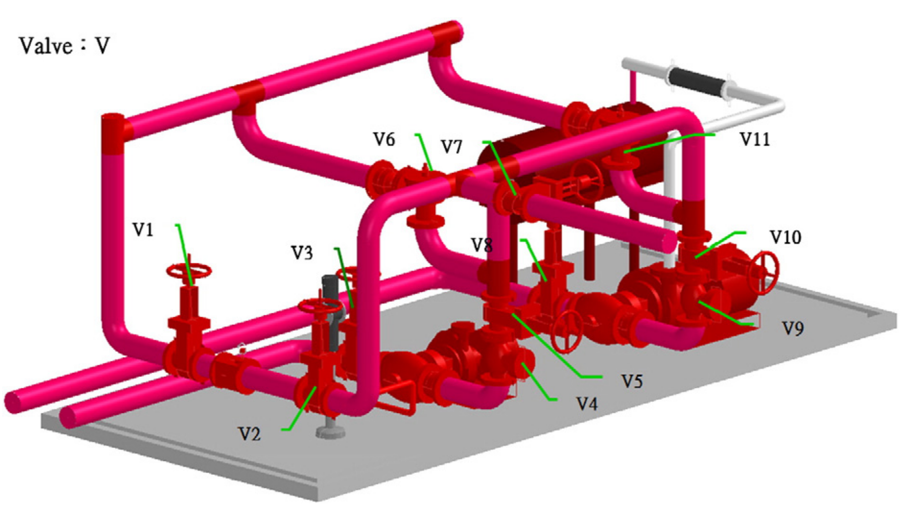


Fig. 13. Fire suppression system showing all valves.

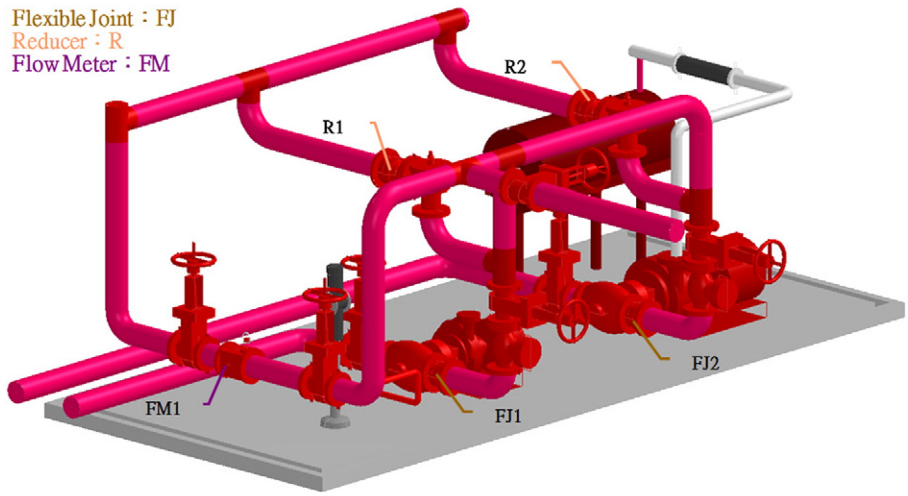


Fig. 14. Fire suppression system showing all flexible joints, reducers, and flow meters.

Step 5 Identify components that fail to meet the weight and/or capacity length criteria and repeat Step 4 and Step 5. All other components move to the next routine related to installation optimization.

2. Analysis of component optimization for installation
The major purpose of this routine is to determine the convenience of site installing the component in the MEP room as generated from Step 2 through Step 5.

Step 6 Analyze component location as it relates to its height and distance to other objects. The height should be within reach of a normal worker and the distance should be sufficient for establishing the connection (e.g., welded or flanged). If the component satisfies these criteria then the analysis is completed. If not, then proceed to Step 7.

Step 7 Determine suitable method to connect components. This might mean installing scaffolding for connection points that are too high or interior welding on connections that are too close to a wall, for example.

Step 8 System division is complete.

3.3. Detailed Discussion of Framework Methodology

This section provides a more detailed description of the algorithm to optimally determine component size and weight considering transportation and jobsite installation criteria. Step 1 involves selecting the MEP system or subsystem. Steps 2–5 relate to the analysis of construction feasibility as it pertains to jobsite delivery (e.g., transportation and on site hoisting equipment limitations). The remaining two steps (6 and 7) optimize on site installation of the components in the MEP room. A detailed description of Step 2 follows.

3.3.1. Establish an Element Database

It is shown in Fig. 3 to include numbering each element in the system using 3D visualization, identifying the dimensions and unit weight of each element, calculating the capacity length and determining the weight of each element.

3.3.1.1. Process.

1. Number each element in the system 3D model. For example, pipes and elbows are numbered with a P designation (e.g., P1 and P2); valves are numbered with a V series such as V1 and V2. Flexible joints are designated by FJ and flow meters are designated by FM.
2. Identify dimensions and unit weight of each element such as flanges and shims, gaskets, pipe and fittings, and valves. A description of each is shown in Table 1.
3. Calculate capacity length of each element.
In accordance with the dimensions found in Table 1, the capacity length is determined by using these values and establishing a

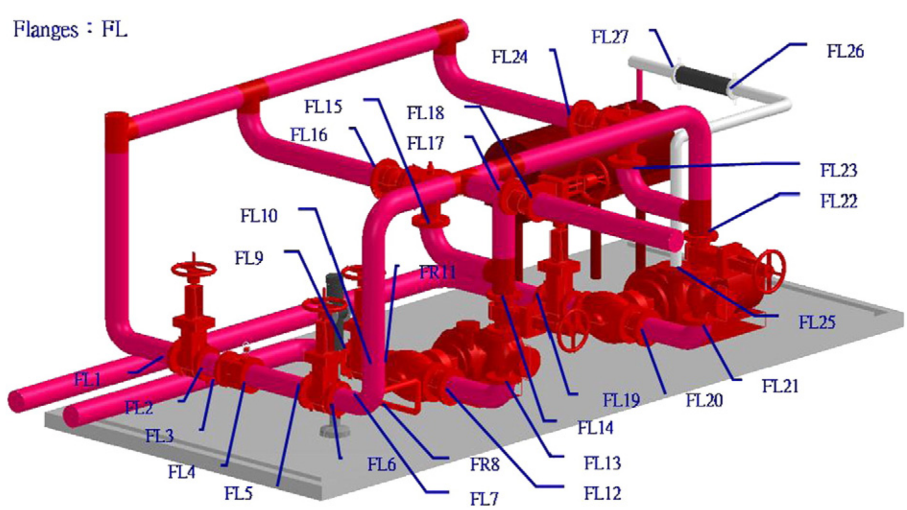


Fig. 15. Fire suppression system showing all flanges.

Table 5
Component spatial length (Dimension: mm; Weight: kg).

No.	Description	Dimension (mm)	Quantity	Weight (kg)	No.	Description	Dimension (mm)	Quantity	Weight (kg)
P1	Pipe	2982	2982	118.38	P39	Cap	102	1	6
P2	Elbow	203,203	1	15	P40	Elbow	305,305	1	15
P3	Pipe	369	369	14.64	P41	Pipe	1457	1457	57.84
P4	Pipe	461	461	18.3	P42	Elbow	305,305	1	15
P5	Elbow	203,203	1	15	P43	Pipe	1457	1457	57.84
P6	Pipe	5678	5678	225.41	P44	Pipe	470	470	18.65
P7	Elbow	203,203	1	15	P45	Pipe	1763	1763	69.99
P8	Pipe	1089	1089	43.23	P46	Pipe	80	80	3.17
P9	Pipe	461	461	18.3	P47	Pipe	80	80	3.17
P10	Elbow	203,203	1	15	P48	Pipe	601	601	9.01
P11	Tee	356,178	1	17	P49	Pipe	604	604	9.06
P12	Pipe	671	671	26.63	P50	Elbow	102,102	1	15
P13	Pipe	471	471	18.69	P51	Pipe	1374	1374	20.61
P14	Elbow	305,305	1	15	P52	Elbow	102,102	1	15
P15	Tee	356,178	1	17	P53	Pipe	1143	1143	17.14
P16	Pipe	544	544	21.59	P54	Pipe	1163	1163	5.85
P17	Pipe	471	471	18.69	P55	Pipe	974	974	4.9
P18	Elbow	305,305	1	15	P56	Elbow	51,51	1	0.9
P19	Elbow	305,305	2	30	P57	Pipe	218	218	1.1
P20	Pipe	2210	2210	87.73	P58	Elbow	51,51	1	0.9
P21	Tee	356,178	1	17	P59	Pipe	898	898	4.52
P22	Pipe	245	245	9.72	V1	Valve	391	1	120
P23	Tee	356,178	1	17	V2	Valve	391	1	120
P24	Pipe	717	717	28.46	V3	Valve	391	1	120
P25	Elbow	305,305	1	15	V4	Valve	476	1	129
P26	Pipe	1447	1447	57.44	V5	Valve	391	1	120
P27	Elbow	203,203	1	15	V6	Valve	312,232	1	125
P28	Pipe	228	228	9.05	V7	Valve	391	1	120
P29	Pipe	730	730	28.98	V8	Valve	391	1	120
P30	Pipe	230	230	9.13	V9	Valve	476	1	129
P31	Pipe	597	597	23.7	V10	Valve	391	1	120
P32	Elbow	203,203	1	15	V11	Valve	312,232	1	125
P33	Pipe	1648	1648	65.42	FJ1	Flexible joint	263	1	23.6
P34	Tee	356,178	1	17	FJ2	Flexible joint	263	1	23.6
P35	Pipe	1446	1446	57.4	R1	Reducer	372	1	23.6
P36	Tee	356,178	1	17	R2	Reducer	372	1	23.6
P37	Pipe	2337	2337	92.77	FM1	Flow meter	349	1	18
P38	Tee	356,178	1	17					

volumetric envelop for each element. For a 305 mm × 305 mm elbow, the capacity length in the y direction is 305 mm plus the inside diameter radius and thickness. Microstation 3D visualization software is used to facilitate this calculation.

4. Calculate weight of each element.

This involves calculating and recording the estimated weight based on the specification provided by the supplier. The weight of pipe material is the length of the pipe material times its weight per unit length.

3.3.1.2. Output.

1. Establish the element database.

This involves giving each element a special number and recording its capacity length and weight which will be used to reduce the system into smaller components.

3.3.2. Remove Equipment from the System

Step 3 involves removing equipment from the MEP system as shown in Fig. 4.

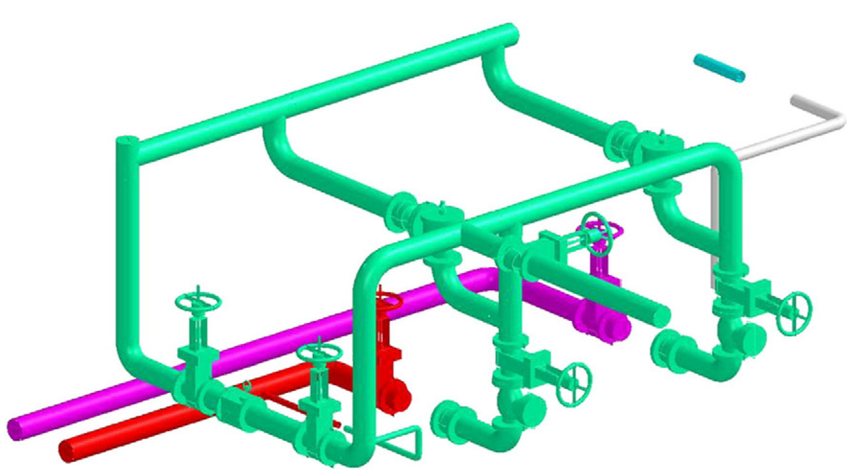


Fig. 16. System without equipment.

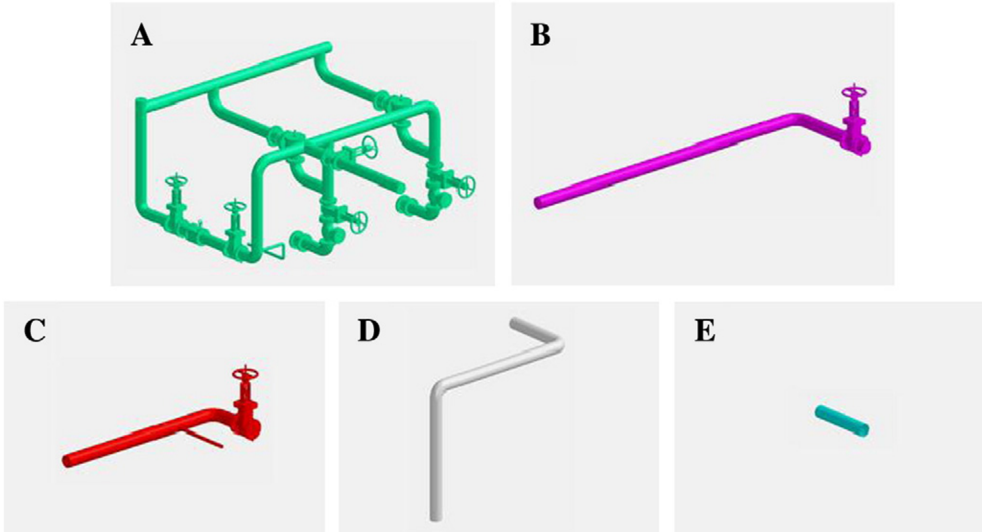


Fig. 17. Basic system decomposition.

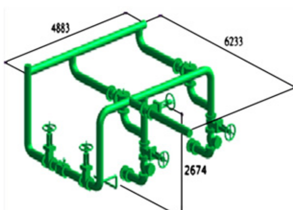
					8" Flexible Joint	8" Reducer	8" Flow Meter	8 " Cap
					FJ1,FJ2	R1,R2	FM1	P39
				Weight/ unit	23.6 kg/pie.	23.6 kg/pie.	18 kg/pie.	6 kg/pie.
				Quantity	2 pie.	2 pie.	1 pie.	1 pie.
				Amount	47.2 kg	47.2 kg	18 kg	6 kg
	8" Gate Valve	8" Swing Check Valve	8" Pressure Relief Valve	8" Tee	8" Elbow	8" Pipe	2" Elbow	2" Pipe
	V1,V2,V5	V4,V9	V6,V11	P11,P15	P5 ,P10	P4,P9,P12,P13,P16	P56	P55
	V7,V10			P21,P23	P14,P18	P17,P20,P22,P24,P26	P58	P57
				P34,P36	P19,P25	P28,P29,P30,P31,P33		P59
				P38	P27,P32	P35,P37,P41,P43,P44		
					P40,P42	P45		
Weight/ unit	120 kg/pie.	129 kg/pie.	125 kg/pie.	17 kg/pie.	15 kg/pie.	0.0397 kg/mm	0.9 kg/pie.	0.005033 kg/mm
Quantity	5 pie.	2 pie.	2 pie.	7 pie.	10 pie.	20061 mm	2 pie.	2090 mm
Amount	600kg	258kg	250kg	119kg	165kg	796.4217kg	1.8kg	10.51897kg

Fig. 18. Decomposition of component A.

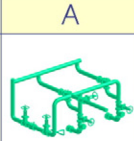
		Number of Component				
		A	B	C	D	E
Fig.						
Weight		2,319	353	277	53	9
	L	4883	6099	3405	1691	601
	W	6233	1915	1273	763	114
	H	2674	1258	1258	1302	114

Fig. 19. Table of components.

One of the main goals of this research is to increase the flexibility in the purchase of equipment and the delivery schedule, which means that the piping system division and fabrication will not be affected. Therefore, the primary task for system division is to remove equipment such as generators, motors, compressors, condensers, and pumps from the entire MEP system.

After equipment removal, the remaining piping system is divided into several components along natural division points, which will subsequently be divided further by judgment and division rules.

3.3.3. Component Optimization for Jobsite Delivery

Step 4 relates to determining the optimal component configuration for jobsite delivery as shown in Fig. 5.

Table 6
Table of construction feasibility (NG: not good).

		Component A			Component B			Component C			Component D			Component E		
		L	W	H	L	W	H	L	W	H	L	W	H	L	W	H
Weight limitation	500 kg	NG			OK			OK			OK			OK		
Capacity length limitation	1650 mm	NG	NG	NG	NG	NG	OK	NG	OK	OK	NG	OK	OK	OK	OK	OK
	2300 mm	NG	NG	NG	NG	OK	OK	NG	OK	OK	OK	OK	OK	OK	OK	OK
	7513 mm	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

3.3.3.1. Process.

1. Judging the load limit of equipment on the jobsite.
   According to the load capacity for the hoisting equipment (e.g., carts and chain blocks) on the jobsite the maximum component weight can be configured to conform to the specifications of this equipment. A single component needs to weigh less than the maximum load limit of the hoisting equipment or the combined weight of several components needs to weigh less than the limit if more than one component is involved.
   The load limit of the components can be expressed in the following formula:

$$\text{Weight of single component} < \text{Min}\,(\text{load maximum of the transportation equipment}, \text{load maximum of the temporary hoist equipment}) \quad (1)$$

   The supporting installation equipment on the jobsite might include handcarts and chain blocks as shown in Table 2:

   A. Transportation equipment (e.g. handcar).
   B. Temporary hoist equipment (e.g. chain block).

2. Judge the capacity length limit of the MEP room.
   Besides the load limits for single components, the shape and the size of each component are also factors for the ease of moving components into the MEP room. It is important to ensure that there is at least one assembled component configuration that would allow for the complete entry into the MEP room. If the component dimensions (either length, width or height) are less than any of the entry dimensions, then, the component's capacity length conforms to these criteria. If not, the limit condition of the capacity length can be expressed in the formula as shown below.

$$\left[\text{Max}\left(\text{component}_{\_long}, \text{component}_{\_width}, \text{component}_{\_height}\right) < \left(\text{MEP Room}_{\_depth}\right)\right] \text{ and } \left[\text{Mid}\left(\text{component}_{\_long}, \text{component}_{\_width}, \text{component}_{\_height}\right) < \text{MAX}\left(\text{Entry of MEP Room}_{\_width}, \text{Entry of MEP Room}_{\_height}\right)\right] \text{ and } \left[\text{Min}\left(\text{component}_{\_long}, \text{component}_{\_width}, \text{component}_{\_height}\right) < \text{Min}\left(\text{Entry of MEP Room}_{\_width}, \text{Entry of MEP Room}_{\_height}\right)\right] \quad (2)$$

3.3.4. First Phase of System Division

Step 5: This step involves creating the components comprising the system weight and capacity dimensions as compared to the allowable values as shown in Fig. 6.

3.3.4.1. Process.

1. Beginning from a piece of equipment or the end of another component, create a list of possible components that terminate at convenient points such as flanges, valve connections and other pieces of equipment.
2. Determine the weight and capacity length of each possible component and identify which one(s) satisfy the criteria.
3. Select the optimal component based on the weight and size being closest to the criteria recognizing that the last component determined in the system may not be optimal in terms of its weight and size.

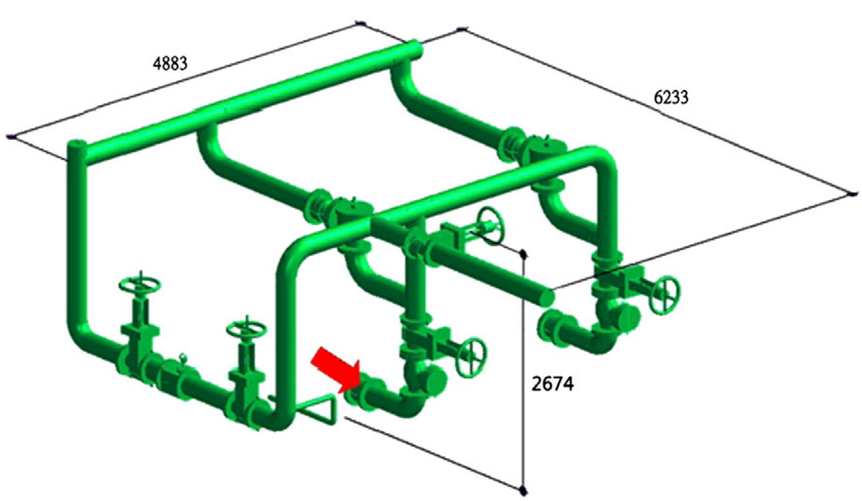


Fig. 20. Possible decompositions of component A.

3.3.5. Component Analyzed by Location

Step 6 relates to optimizing the installed location by considering the overhead work height and distance between connection points and other structures (such and the walls, floor, or ceiling) as shown in Fig. 7.

3.3.5.1. Process.

1. Assess component division to avoid overhead work and narrow operating space. For this exercise the average height of 1700 mm for an adult male and 1600 mm for an adult female, and an acceptable operating height is approximately at eye level (assume 1580 to 1600 mm) as shown in Fig. 8. Narrow construction operating space is defined as the side width of an employee which is approximately 600 mm and the length from the finger tip to the ground is 750 mm, which means that the operating capacity for the location of division is 600 mm horizontal and 750 mm vertical.
2. If the system division cannot avoid overhead work and narrow space operations, the separation process needs to adjust the division location including the following considerations:

   A. If the replaceable location of division distributes the components in an inefficient manner.
   B. If the replaceable location of division increases the number of break points in the model, the goal is to decrease the number of break points in the system.
   C. If the space for the replaceable location of division is too narrow.
   D. If there is a more optimal location for the division.

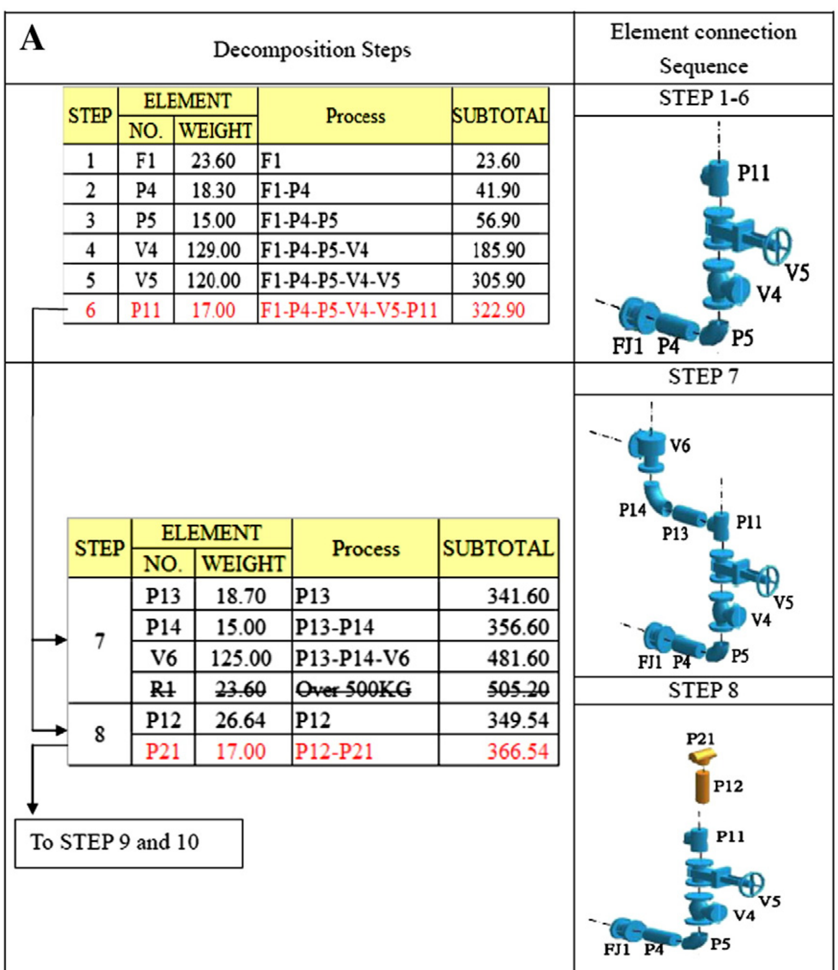
3.3.6. Determine the Suitable Methods to Connect Components

Step 7 after considering the division location, if the location of division cannot be changed, the suitable methods for connecting components need to be considered as shown in Fig. 9.

3.3.7. Process

1. Judgment criteria for connection methods need to consider the following guiding principles:

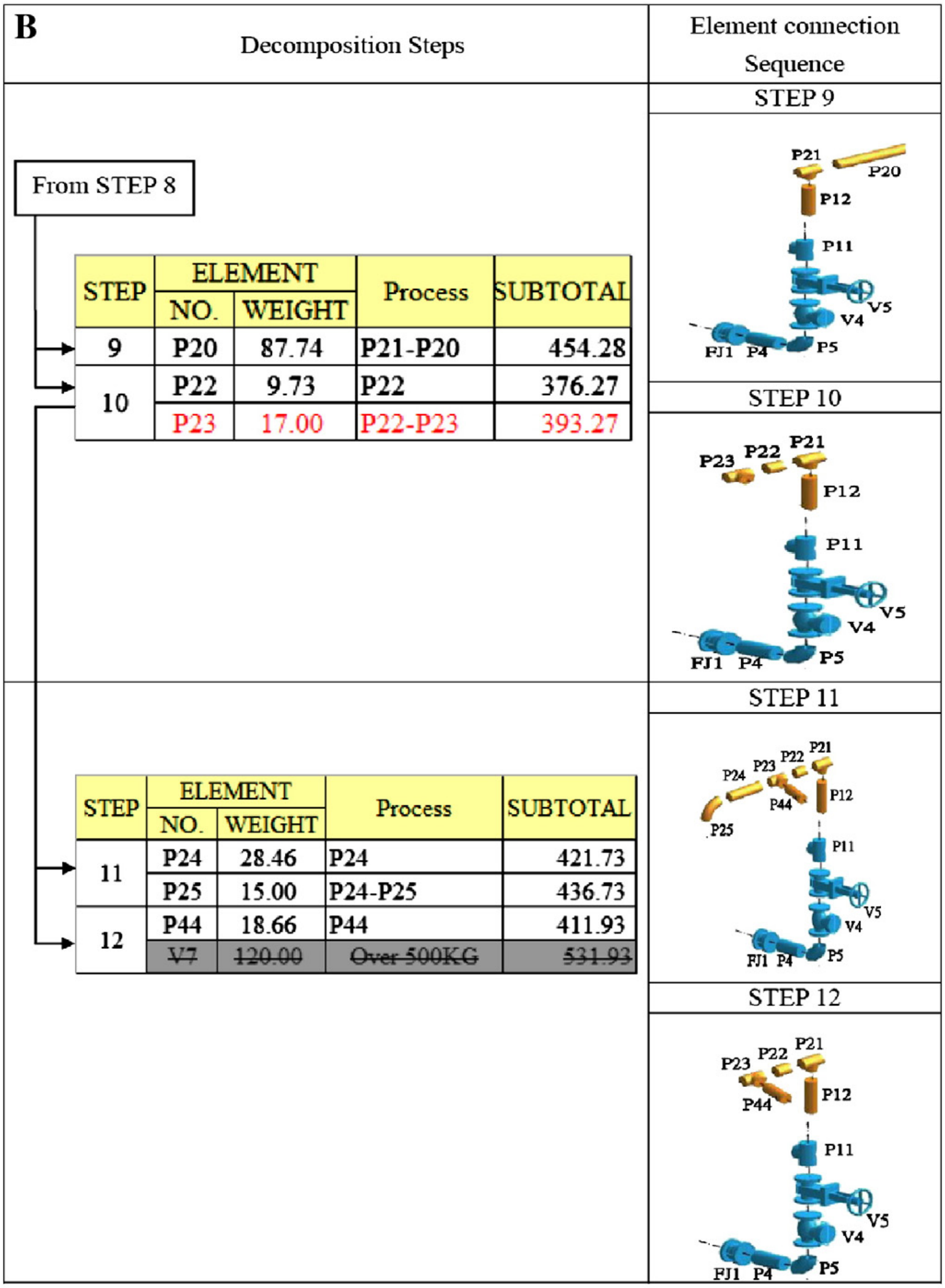
   A. Wider is better than narrower for flanges.
   The length of a wrench is approximately 200 mm. If the division location is at a flange, the required operating space for using the wrench to turn the bolts needs more than 200 mm and as shown in Fig. 10.
   B. Avoid narrow-gap welding.
   Narrow-gap welding means that the closest point between the location of division, wall, floor or ceiling is less than 3 mm. It involves interior edge welding using a mirror or other suitable method. This technique is costly and time consuming and should be avoided if at all possible.
   C. Avoid bent pipe coupling.
   Coupling can be locked tightly by rotating one of the two components. Since bent pipe needs more operating room for rotation, bent pipe couplings should be avoided in the narrow or smaller MEP rooms.



STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
1	F1	23.60	F1	23.60
2	P4	18.30	F1-P4	41.90
3	P5	15.00	F1-P4-P5	56.90
4	V4	129.00	F1-P4-P5-V4	185.90
5	V5	120.00	F1-P4-P5-V4-V5	305.90
6	P11	17.00	F1-P4-P5-V4-V5-P11	322.90

STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
7	P13	18.70	P13	341.60
	P14	15.00	P13-P14	356.60
	V6	125.00	P13-P14-V6	481.60
	~~R1~~	~~23.60~~	~~Over 500KG~~	~~505.20~~
8	P12	26.64	P12	349.54
	P21	17.00	P12-P21	366.54

Fig. 21. (A) Decomposition procedures of component A-1. (B) Decomposition procedures of component A-1.



METHOD	PROCESS	WEIGHT
1	FJ1-P4-P5-V4-V5-P11-P13-P14-V6	481.60
2	FJ1-P4-P5-V4-V5-P11-P12-P21-P22-P23-P24-P25	436.73
3	FJ1-P4-P5-V4-V5-P11-P12-P21-P22-P23-P44	411.93
4	FJ1-P4-P5-V4-V5-P11-P12-P21-P20	454.28

Fig. 21 (*continued*).

D. Avoid long pipe coupling.
Long pipe is difficult to manipulate or transport.

2. If the above conditions cannot be avoided, the suggestions for the connection methods are as follows and as shown in Table 3:

From Step 1 to Step 7, the system can be decomposed into several smaller transportable components which conform to the weight and space limitations.

4. Case Study

In mechanical, electrical, plumbing and fire suppression systems in construction projects, both systems can be separated into two general parts, equipments and pipes (refer to Table 4). The algorithm proposed in this study aims to deal with all the system with pipe, so that no matter what system it is, as long as the system includes equipments and pipes, it can be decomposed by using this method. Moreover, due to fire

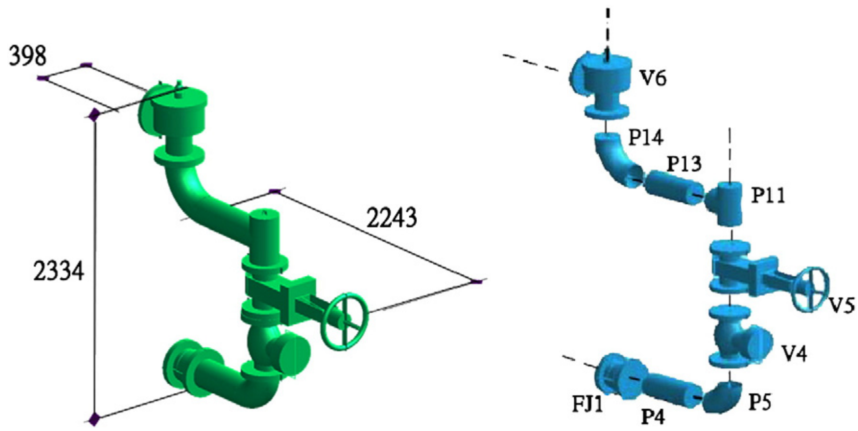


Fig. 22. Decomposition result of component A-1.

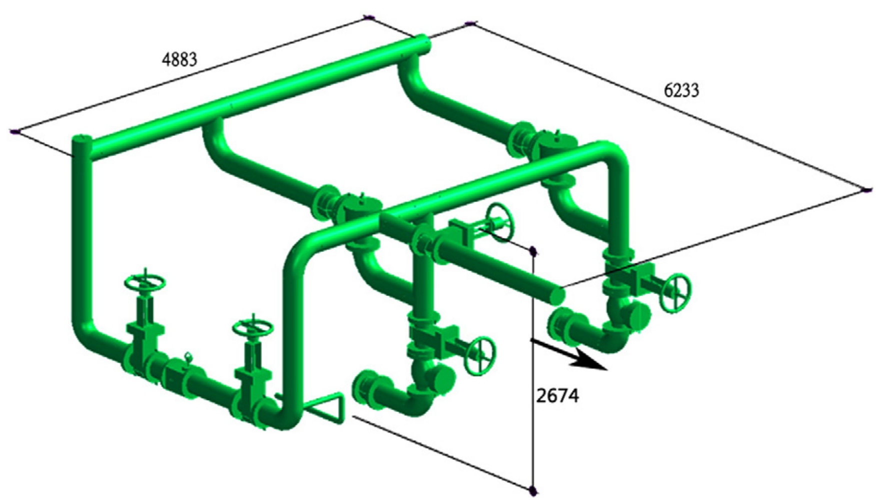


Fig. 23. New component A-2.

suppression systems are usually in the room of the corner of the basement with the limited construction space and complex pipe combination, this study use fire suppression system for a case study.

This research methodology has been applied to a fire suppression system project in Taiwan. The project was located in Tainan Science Industrial Park which is in Taiwan and cost approximately NT

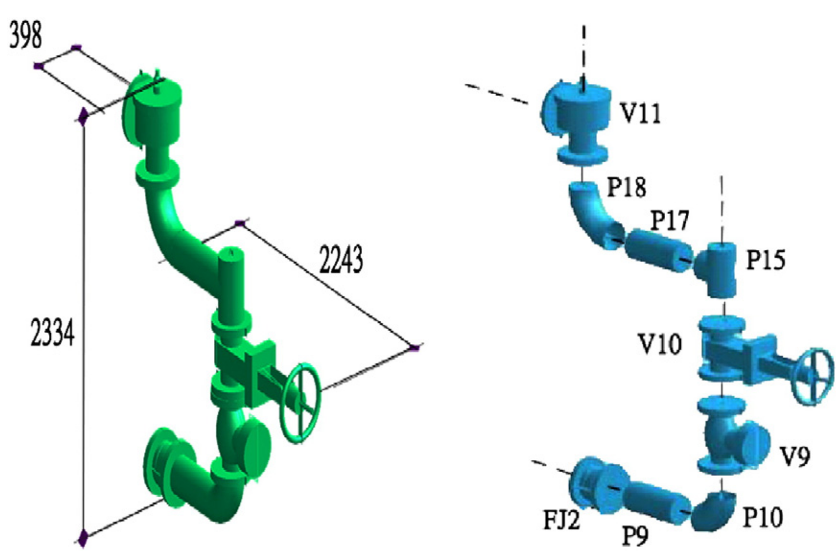


Fig. 24. Decomposition result of component A-2.

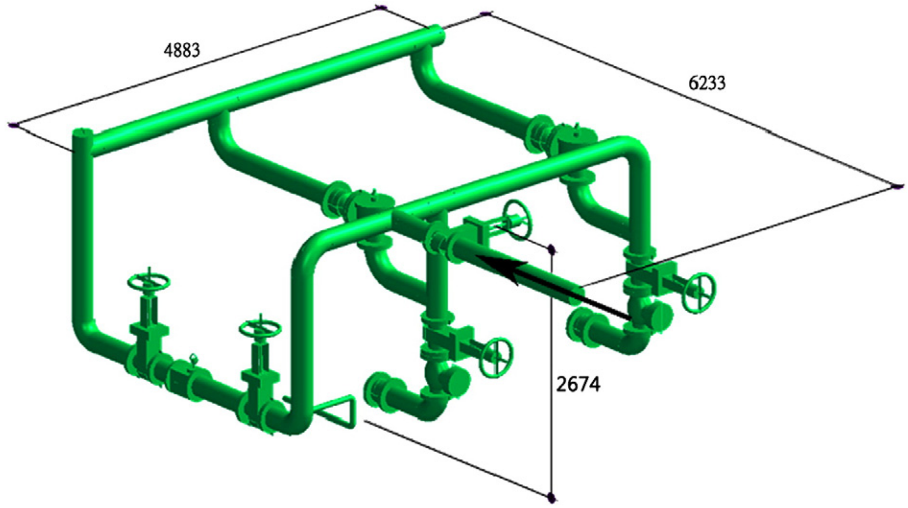


Fig. 25. New component A-3.

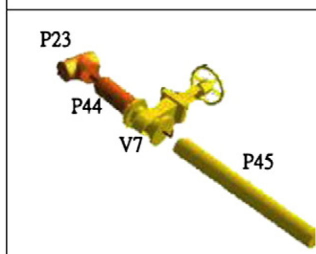
A

Decomposition Steps

Element connection Sequence

STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
1	P45	69.99	P45	69.99
2	V7	120.00	P45-V7	189.99
3	P44	18.66	P45-V7-P44	208.65
4	P23	17.00	P45-V7-P44-P23	225.65

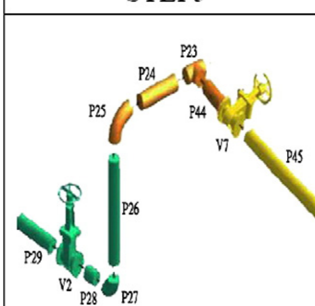
STEP1-4



STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
5	P24	28.46	P24	254.12
	P25	15.00	P24-P25	269.12
	P26	57.45	P24-P25-P26	326.56
	P27	15.00	P24-P25-P26-P27	341.56
	P28	9.05	P24-P25-P26-P27-P28	350.61
	V2	120.00	P24-P25-P26-P27-P28-V2	470.61
	P29	28.98	P24-P25-P26-P27-P28-V2-P29	499.59
	~~FM1~~	~~18.00~~	~~Over 500KG~~	~~517.59~~
6	P22	9.73	P22	235.38
	P21	17.00	P22-P21	252.38

To STEP 7 and 8

STEP5



STEP6

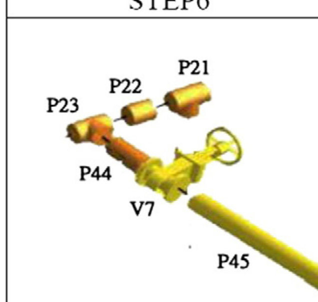


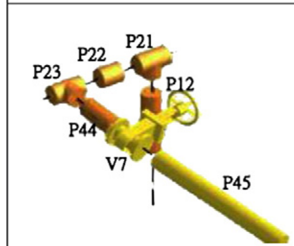
Fig. 26. (A) Decomposition procedures for component A-3. (B) Decomposition procedures for component A-3.

B Decomposition Steps | Element connection Sequence

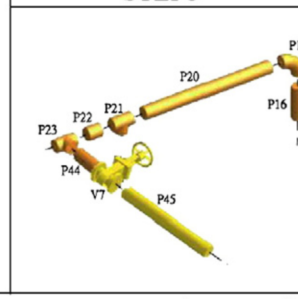
From STEP 6

STEP	ELEMENT		Y/N	Process	SUBTOTAL
	NO.	WEIGHT			
7	P12	26.64	V	P12	279.02
8	P20	87.74	V	P20	340.11
	P19	30.00	V	P20-P19	370.11
	P16	21.60	V	P20-P19-P16	391.71

STEP7



STEP8



1	P45-V7-P44-P23-P24-P25-P26-P27-P28-V2-P29				499.59
2	P45-V7-P44-P23-P22-P21-P12				279.02
3	P45-V7-P44-P23-P22-P21-P20-P19-P16				391.71
→	P45-V7-P44-P23 -	P22-P21-	P12		461.86
		-	P20-P19-P16		
		- P24-P25			

Fig. 26 (*continued*).

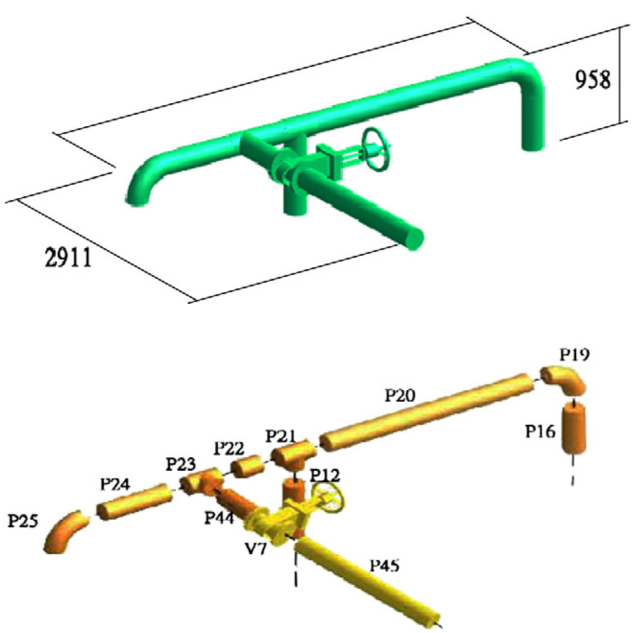


Fig. 27. Decomposition result for component A-3.

$5,000,000 ($150,000 USD) and the construction period was 1 year. Fig. 11 shows the configuration of the MEP room in this building.

4.1. Analysis of Component Optimization for Jobsite Delivery

4.1.1. Step 1 Select an MEP System

This example involves a fire suppression system which will be situated in a room with the following dimensions (room depth: 7512.5 mm, entry width: 2300 mm, entry height: 1650 mm., refer to Fig. 11).

4.1.2. Step 2 Establish Element Database

The MEP system, as shown in the 3D visualization is decomposed into all of the elements and numbered, including pipe castings (refer to Fig. 12), valves (refer to Fig. 13), parts such as flexible joints, flow meters, and reducers (refer to Fig. 14), and flanges (refer to Fig. 15).

By combining the component number, spatial length and weight, a database of components (refer to Table 5) is established to become the basis for efficiently dividing the system into its components.

4.1.3. Step 3 Remove System Equipment

Utilizing 3D graphics, the system can be broken down into several components or elements after removing all equipment from the system as shown in Figs. 16 and 17.

4.1.4. Step 4 Component Optimization for Jobsite Delivery

After equipment removal, the system is divided into several components and elements at natural division points. The basic elemental information for component A is shown in Fig. 18.

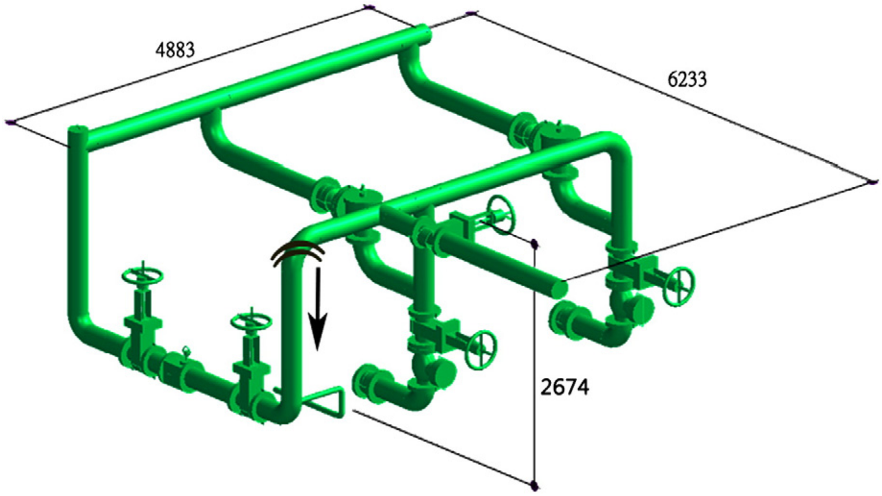


Fig. 28. New component A-4.

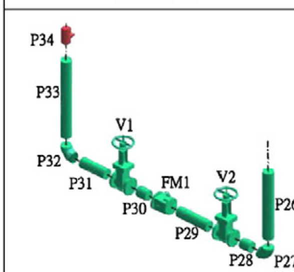
Decomposition Steps	Element connection Sequence

STEP	ELEMENT		Process	SUBTOTAL
	NO.	WEIGHT		
1	P26	57.45	P26	57.45

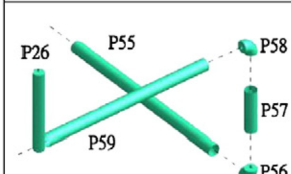
STEP 1

STEP	ELEMENT		Process	SUBTOTAL
	NO.	WEIGHT		
2	P27	15.00	P27	72.45
	P28	9.05	P27-P28	81.50
	V2	120.00	P27-P28-V2	201.50
	P29	28.98	P27-P28-V2-P29	230.48
	FM1	18.00	P27-P28-V2-P29-FM1	248.48
	P30	9.13	P27-P28-V2-P29-FM1-P30	257.61
	V1	120.00	P27-P28-V2-P29-FM1-P30-V1	377.61
	P31	23.70	P27-P28-V2-P29-FM1-P30-V1-P31	401.31
	P32	15.00	P27-P28-V2-P29-FM1-P30-V1-P31-P32	416.31
	P33	65.43	P27-P28-V2-P29-FM1-P30-V1-P31-P32-P33	481.74
	P34	17.00	P27-P28-V2-P29-FM1-P30-V1-P31-P32-P33-P34	498.74
3	P59	4.52	P59	61.97
	P58	0.90	P59-P58	62.87
	P57	1.10	P59-P58-P57	63.96
	P56	0.90	P59-P58-P57-P56	64.86
	P55	4.90	P59-P58-P57-P56-P55	69.76

STEP 2



STEP 3



1	P26-P59-P58-P57-P56-P55	69.76
2	P26-P27-P28-V2-P29-FM1-P30-V1-P31-P32-P33-P34	498.74
→	P26-P59-P58-P57-P56-P55 -P27-P28-V2-P29-FM1-P30-V1-P31-P32-P33	494.05

Fig. 29. Decomposition procedures for component A-4.

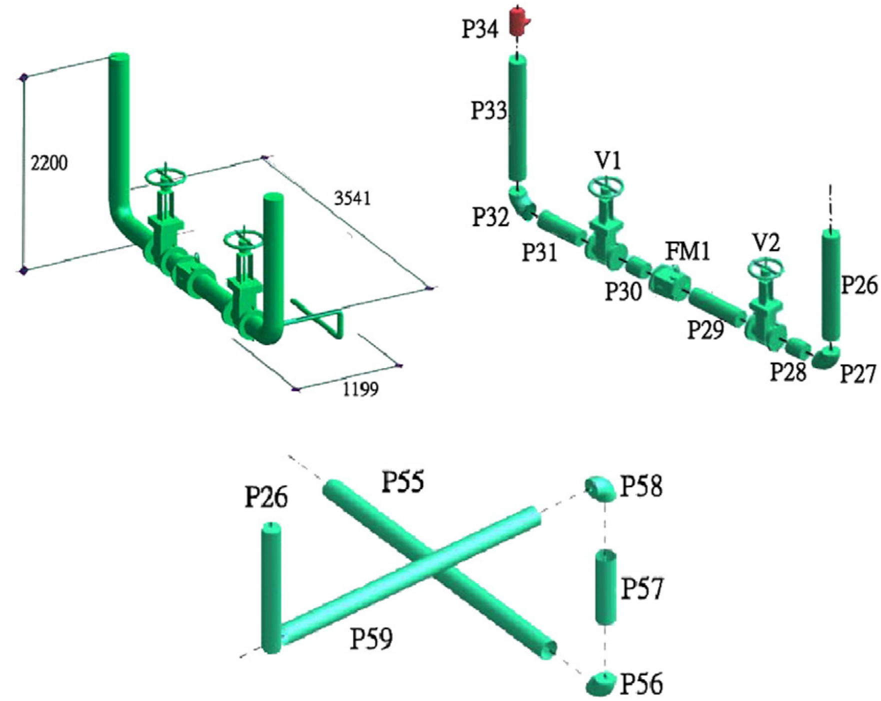


Fig. 30. Decomposition results for component A-4.

Fig. 19 provides basic information about each component such as its weight and dimensions (weight: kg_f; spatial length: mm).

1. Judging the load limitation of equipment at the jobsite.
   The hoisting equipment at this jobsite includes a handcart and a chain block both of which have load limits of 500 kg_f. According to formula (1) and Table 2, the loading limitation of decomposition is 500 kg_f.

2. Judging length limitation of MEP room.
   The entry size of the MEP room in this case study is W1650 mm* H2300 mm*D7512.5 mm. According to formula (2) (1650 mm, 2300 mm, and 7513 mm) is the limitation of spatial length of each components, and then the decomposition of every component has to comply with this consideration.
   Components can be judged if they can be transported to the jobsite (weight limitation has to be smaller than 500 kg_f and spatial length limitation is 1650 mm, 2300 mm, and 7513 mm). In Fig. 19, component A (spatial length: 4883 mm, 6233 mm, and 2674 mm, and weight: 2319 kg_f) is not in compliance with the limitations. The results from the construction feasibility analysis are shown in Table 6.

4.1.5. Step 5 First Phase Division

Components B, C, D and E meet the requirements, except for component A, which does not satisfy the limitations. Therefore, component A needs to be broken down further.

1. Decomposition of component A (A-1).
   According to Fig. 20, there are several ways to break down component A from the arrowhead (refer to Fig. 21).
   Starting from F1, the decomposition path is F1-P4-P5-V4-V5-P11 (refer to Fig. 21, steps 1–6), at P11 there are two elements, P12 and P13, which are connected to P11. Choosing P13, the decomposition

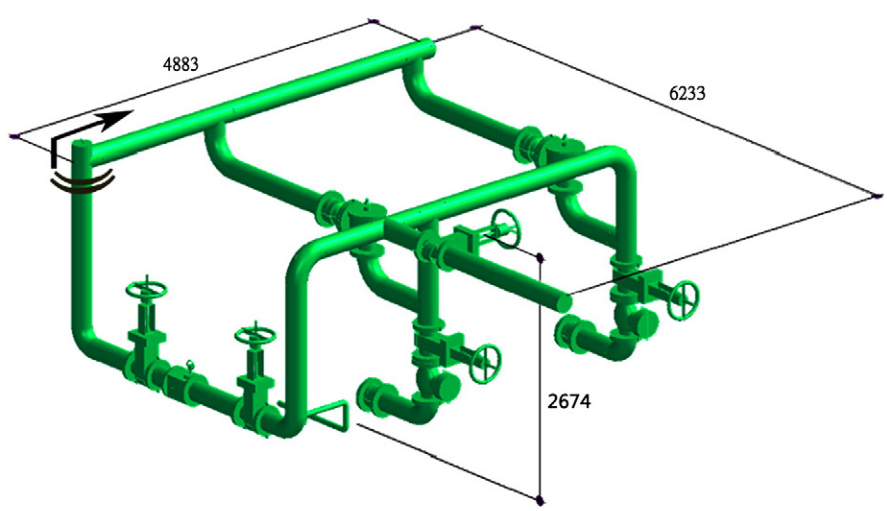


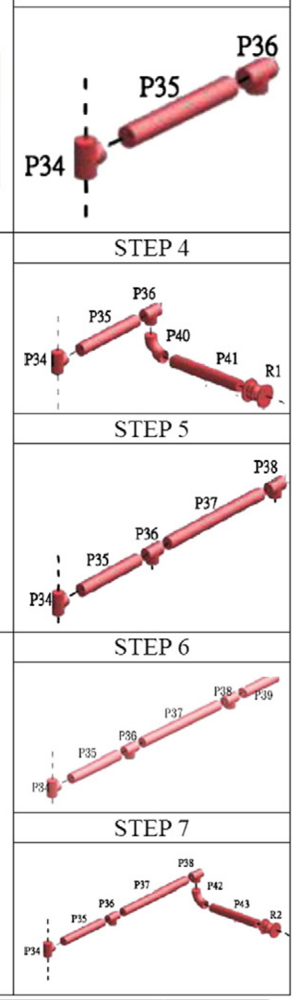
Fig. 31. New component A-5.

Decomposition Steps	Element connection Sequence

STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
1	P34	17.00	P34	17.00
2	P35	57.41	P34-P35	74.41
3	P36	17.00	P34-P35-P36	91.41

STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
4	P40	15.00	P40	15.00
	P41	57.84	P40-P41	72.84
	R1	23.60	P40-P41-R1	96.44
5	P37	92.78	P37	92.78
	P38	17.00	P37-P38	109.78

STEP	ELEMENT NO.	ELEMENT WEIGHT	Process	SUBTOTAL
6	P39	6.00	P39	115.78
7	P42	15.00	P42	124.78
	P43	57.84	P42-P43	182.62
	R2	23.60	P42-P43-R2	206.22



1	P34-P35-P36-P40-P41-R1		96.44
2	P34-P35-P36-P37-P38-P39		115.78
3	P34-P35-P36-P37-P38-P42-P43-R2		206.22
→	P34-P35-P36	-P40-P41-R1	400.07
		-P37-P38-P39	
		-P42-P43-R2	

Fig. 32. Decomposition procedures for component A-5.

path is P13-P14-V6 (refer to Fig. 21, step 7), thus one obtains the decomposition from method 1 which is F1-P4-P5-V4-V5-P11-P13-P14-V6 with weight in 482 kg_f and spatial length of (398 mm, 2243 mm, 2334 mm).

At P11, if P12 were chosen, the next element is P21 (refer to Fig. 21, step 8), at P21 there are two elements, P20 and P22, which are connected to P21. Choosing P20, the decomposition path is P21-P20 (refer to Fig. 21, step 9), thus one could use decomposition method 4 and obtain F1-P4-P5-V4-V5-P11-P12-P21-P20 with a weight of 454.28 kg_f.

If P22 were chosen at P21, the next element is P23 (refer to Fig. 21, step 10) and there are two elements, P24 and P44, which are connected to P23. One could obtain, using decomposition method 2, the following: F1-P4-P5-V4-V5-P11-P12-P21-P22-P23-P24-P25 with a weight of 436.73 kg_f by choosing P24 (refer to Fig. 21, step 11) or using decomposition method 3 the following sequence F1-P4-P5-V4-V5-P11-P12-P21-P22-P23-P44 with weight in 411.93 kg_f by choosing P44 (refer to Fig. 21, step 12).

Since the end-point of decomposition (for method 1) is a flange connection which weighs approximately 500 kg_f and the least locations of division during three types of decomposition methods in Fig. 21, decomposition method 1 is utilized for decomposing component A in which the new component (A-1) includes F1-P4-P5-V4-V5-P11-P13-P14-V6 with weight in 482 kg_f and spatial length of (398 mm, 2243 mm and 2334 mm) and is shown in Fig. 22.

2. Starting from the arrowhead to decompose the component A-2 (refer to Fig. 23), A-2 includes F2-P9-P10-V9-V10-P15-P17-P18-V11 by using the same decomposition method like A-1 and the result is shown in Fig. 24.
3. Decomposition of component A-3:

   In Fig. 25, component A-3 is broken down in the direction of the arrow whose decomposition procedures are shown in Fig. 26. In

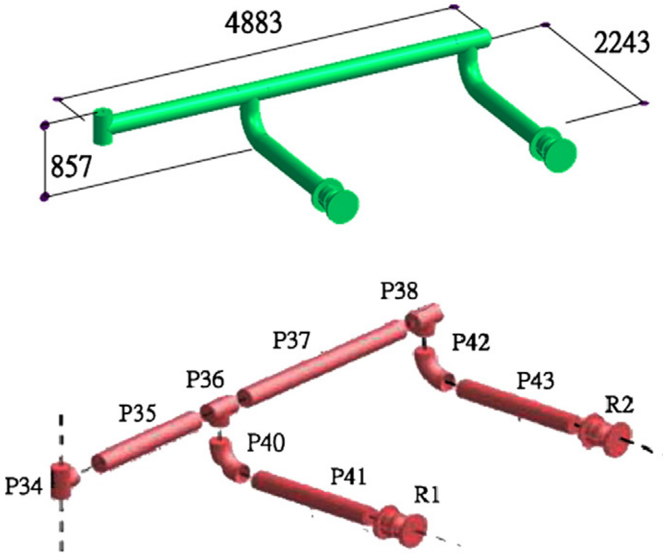


Fig. 33. Decomposition results for component A-5.

Fig. 26, there are three types of decomposition methods used. If methods 2 and 3 are not used for A-3, A-3 will be shaped such that it cannot merge with other components. Hence, methods 2 and 3 are combined and components P24 and P25 are included using method 1 to achieve a weight closest to 500 kg_f. The component A-3 can be configured with some adjustment, including P45-V7-P44-P23-P22-P21-P12-P20-P19-P16-P24-P25. The shape of component is shown in Fig. 27 with a weight of 462 kg_f and spatial length of (4712 mm, 2911 mm and 958 mm).

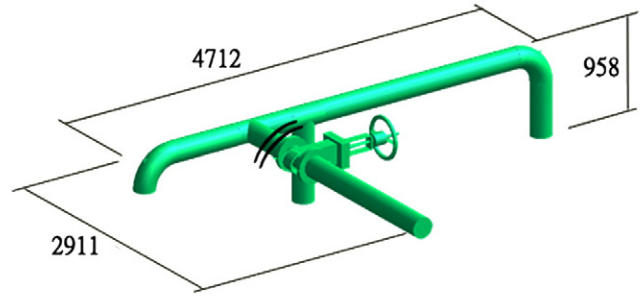


Fig. 35. Decomposition of component A-3.

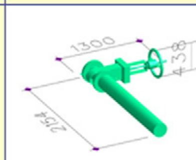
		Number of Component	
		A-3-1	A-3-2
Fig.			
Weight		190	272
Space	L	1300	4712
	W	2154	757
	H	438	958

Fig. 36. Further decomposition of component A-3.

		Number of Component				
		A-1	A-2	A-3	A-4	A-5
Fig.						
Weight		482	482	462	494	400
Space	L	398	398	4712	1199	4883
	W	2243	2243	2911	3541	2243
	H	2334	2334	958	2200	857

※: A = (A-1)+(A-2)+(A-3)+(A-4)+(A-5) = 2318(kg)

Fig. 34. General decomposition results for component A.

Table 7
Construction feasibility of component A (NG: not good).

		Component A-1			Component A-2			Component A-3			Component A-4			Component A-5		
		L	W	H	L	W	H	L	W	H	L	W	H	L	W	H
Weight limitation	500 kg	OK			OK			OK			OK			OK		
Capacity length limitation	1650 mm	OK	NG	NG	OK	NG	NG	NG	NG	OK	OK	NG	NG	NG	NG	OK
	2300 mm	OK	OK	NG	OK	OK	NG	NG	NG	OK	OK	NG	OK	NG	OK	OK
	7513 mm	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

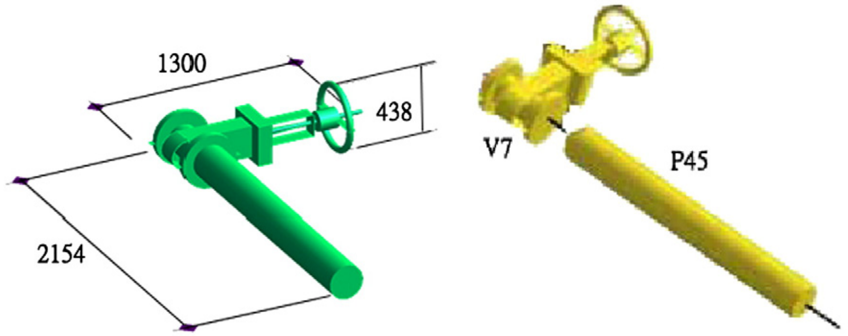


Fig. 37. Decomposition results for component A-3-1.

A. Decomposition of component A-4:
In Fig. 28, component A-4 is broken down in the direction of the arrow, whose decomposition procedures are shown in Fig. 29. In Fig. 29, there are three types of decomposition methods of which method 2 is the best option. However, if method 1 cannot merge into A-4, it will create a configuration which cannot merge into other components. Therefore, P27-P33 from method 2 is added into method 1 to obtain a weight closest to 500 kg_f. Component A-4 can be assembled with some adjustment, including the following components: P26-P59-P58-P57-P56-P55-P27-P28-V2-P29-FM1-P30-V1-P31-P32-P33. The shape of the component is shown in Fig. 30 with a weight of 494 kg_f and spatial length of 1199 mm, 3531 mm and 2200 mm.

B. Decomposition of component A-5:
In Fig. 31, component A-5 is decomposed in the direction of the arrow, whose decomposition procedures are shown in Fig. 32. In Fig. 32, there are three types of decomposition methods, for which the total weight is not over 500 kg_f. Therefore, three methods are combined to make component A-5's weight closest to 500 kg_f. Component A-5 can be optimized with adjustment, including the following components: P34-P35-P36-P40-P41-R1-P37-P38-P39-P42-P43-R2. The shape of the component is shown in Fig. 33 with a weight of 400 kg_f and spatial length of 4883 mm by 2243 mm by 857 mm.

C. Component A is decomposed into five smaller parts by the above mentioned decomposition method which is shown in Fig. 34 and component A = (A-1) + (A-2) + (A-3) + (A-4) + (A-5) = 2318 kg_f.

A check is needed to determine whether each component matches with construction limitations at the jobsite; the results are shown in Table 7.

After comparison, Component A-3 does not conform to the spatial length limitation. Therefore, component A-3 is decomposed as shown in Fig. 35.

Component A-3 is broken down at the valve connection and now becomes component A-3-1 and A-3-2, as shown in Fig. 36.

A check is now made to determine if components A-3-1 (refer to Fig. 37) and A-3-2 (refer to Fig. 38) match the limitations at the jobsite as shown in Table 8.

When component A is decomposed into 6 smaller parts (refer to Fig. 39), each component now satisfies the limitations at the jobsite.

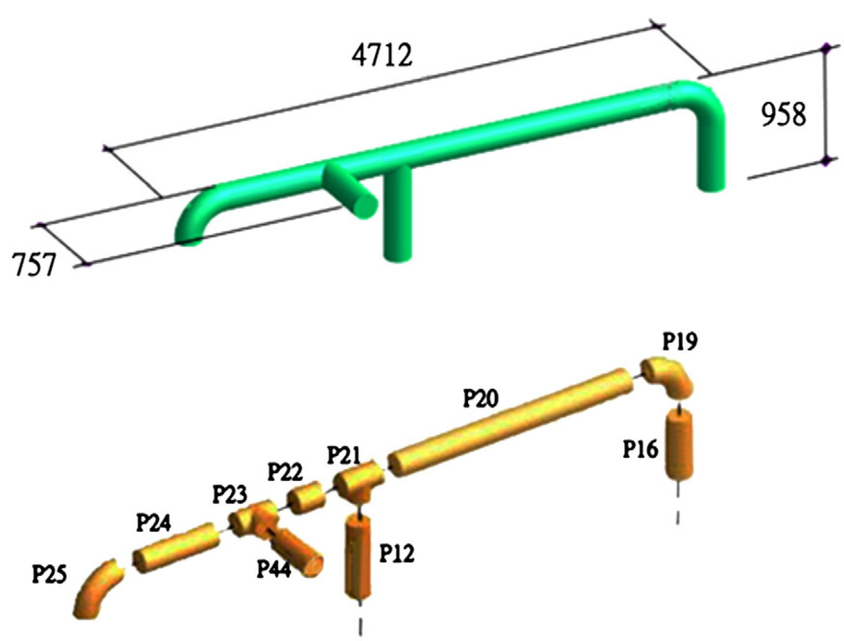


Fig. 38. Decomposition results for component A-3-2.

Table 8
Construction feasibility of component A-3 (NG: not good).

		Component A-3-1			Component A-3-2		
		L	W	H	L	W	H
Weight limitation	500 kg	OK			OK		
Capacity length limitation	1650 mm	OK	NG	OK	NG	OK	OK
	2300 mm	OK	OK	OK	NG	OK	OK
	7513 mm	OK	OK	OK	OK	OK	OK

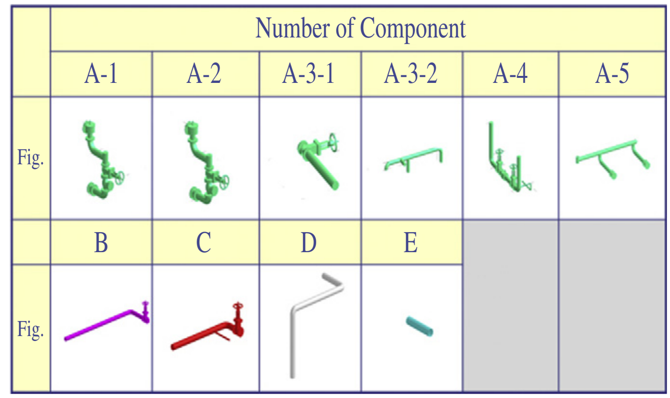


Fig. 40. The first phase of system decomposition.

Accordingly, the first phase of system decomposition, as shown in Fig. 40, is completed.

4.2. Analysis of Component Optimization for Installation

The main purpose of this next phase is to review component optimization for installation including the rationality of the location of division and its fabrication method.

4.2.1. Step 6 Analyzes the Component Location

Based on the result of system decomposition determined from Steps 2–5, the rationality for field installation of every division location is compared and presented in Fig. 41.

4.2.2. Step 7 Determines the Suitable Method to Connect Components

In Fig. 41, every location using this division is contrary to the principle of avoiding overhead work, since all locations involve overhead connections. In Fig. 42, the location of division is adjusted to A–D where A–D are located at Valve 1 (left A and right B) and Valve 2 (left C and right D) in order to avoid the difficulty of fabrication using overhead work.

Due to the fact that component A is part of a component which requires overhead work, and even though point A to D is the location of a division, it is difficult to avoid other locations of division in order to reduce overhead work under the principles of a rational decomposition (i.e., trying to decrease the number of components).

Since some overhead work cannot be avoided, the feasibility of locating the division at a simpler connection point can be considered by replacing the welding process. Alternative decomposition methods for the location of division are shown in Table 9. Adopting alternative methods for every joint is not feasible due to the component weight restriction and overhead working principle.

Through the decomposition procedure from steps 1 through 5, the system can be divided into several smaller components or elements in accordance with the load and the length limitation requirements. Furthermore, considering the rationality for field installation of every division location to avoid the overhead work and considering the suitable connecting methods for every joint could facilitate the installation process. The results of system decomposition are collated and numbered shown in Fig. 43.

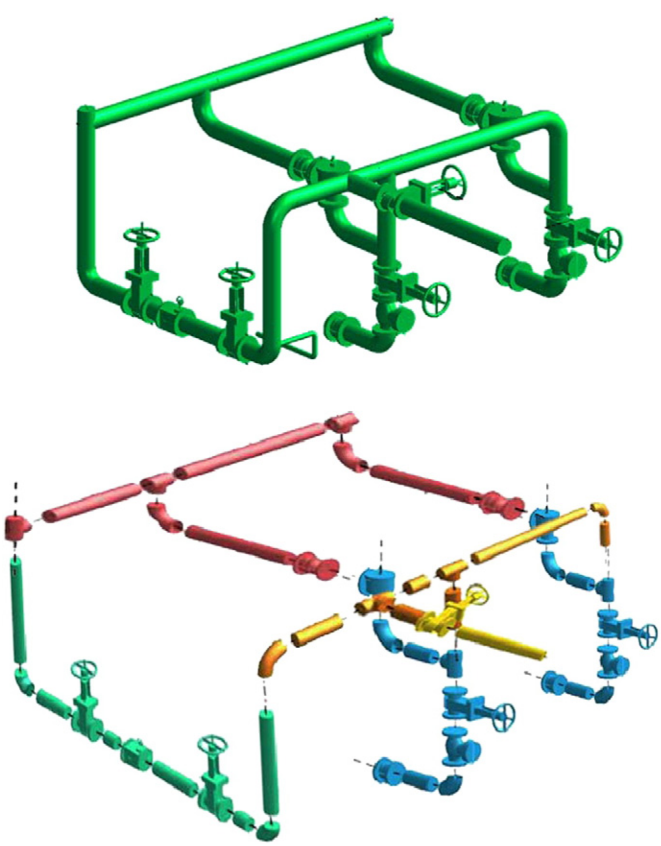


Fig. 39. Decomposition result of component A.

4.3. Method Verification and Validation

The decomposed result is confirmed by three experts, and the comparison of the actual work record with traditional construction method estimate by three experts proved the validity of this method.

4.3.1. Expert Background

The opinions of three experts specializing in the MEP domain were interviewed to validate this decomposition procedure. The backgrounds of each expert are shown in Table 10.

4.3.2. Expert Opinion

The final system decomposition results need to be validated by experts. Opinions related to partial components from experts are shown in Table 11.

4.3.3. Decomposition Verification

Since component B is joint by a long pipe and flange, it is easily broken down due to its nonuniform weight distribution which creates difficulties during transportation. Therefore, component B is decomposed at the flange again (refer to Fig. 44).

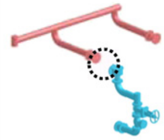
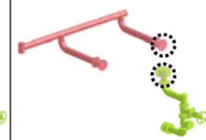
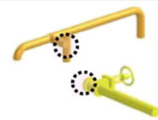
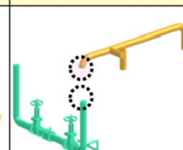
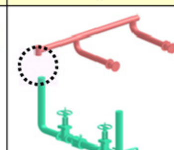
		A-1 ‖ A-3-2	A-1 ‖ A-5	A-2 ‖ A-3-2	A-2 ‖ A-5
					
		Wilding	Flange	Wilding	Flange
Assemble Location	Avoid Overhead Work	The height is 1851mm NG	The height is 2093mm NG	The height is 1851mm NG	The height is 2093mm NG
	Avoid Narrow Operation Space	OK	OK	OK	OK
Assemble Method	Avoid Narrow Space for Flange	--	OK	OK	OK
	Avoid Narrow Space Wilding	The distance to wall is 1249mm OK	--	The distance to wall is 1249mm OK	--
	Avoid Bend Pipe Coupling	--	--	--	--
	Avoid Long Pipe Coupling	--	--	--	--
		A-3-1 ‖ A-3-2	A-3-2 ‖ A-4	A-4 ‖ A-5	
					
		Flange	Wilding	Wilding	
Assemble Location	Avoid Overhead Work	The height is 2678mm NG	The height is 2395mm NG	The height is 2596mm NG	
	Avoid Narrow Operation Space	OK	OK	OK	
Assemble Method	Avoid Narrow Space for Flange	--	OK	OK	
	Avoid Narrow Space Wilding	--	The distance to wall is 290mm OK	The distance to wall is 290mm OK	
	Avoid Bend Pipe Coupling	--	--	--	
	Avoid Long Pipe Coupling	--	--	--	

Fig. 41. Optimization for location of division.

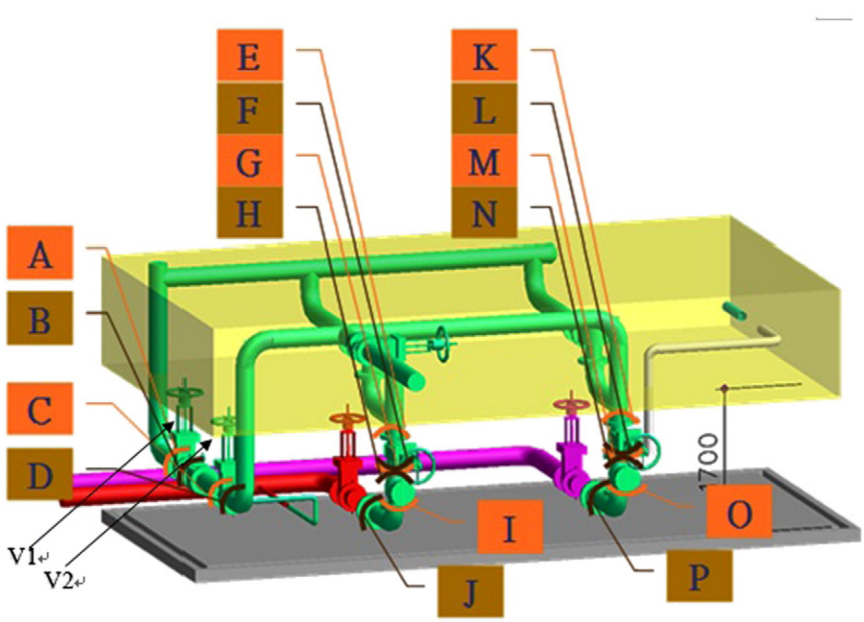


Fig. 42. Location of division.

Table 9
Optimization for connecting methods for division.

Fabrication location	Replaceable methods			
	Coupling	Flange	Union	Conclusion
A-1//A-3-2	Not good 1. overweight/oversize component 2. Fabrication space	Not good 1. Adding material and weld bond 2. Increasing possibility of leaking	Not good No union with 8 in. caliber	Adopting welding method
A-2//A-3-2	Not good 1. overweight/oversize component 2. Fabrication space	Not good 1. Adding material and weld bond 2. Increasing possibility of leaking	Not good No union with 8 in. caliber	Adopting welding method
A-3-2//A-4	Not good 1. overweight/oversize component 2. Fabrication space	Not good 1. Adding material and weld bond 2. Increasing possibility of leaking	Not good No union with 8 in. caliber	Adopting welding method

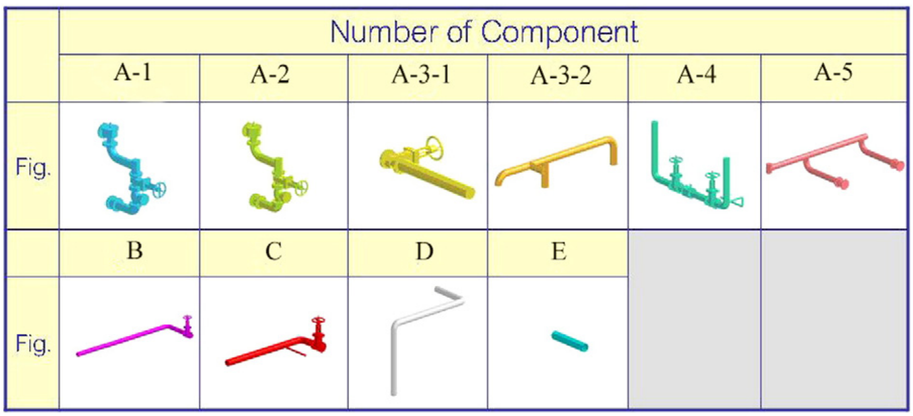
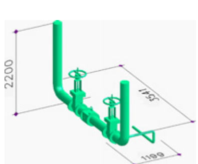


Fig. 43. The optimal system decomposition.

Table 10
Expert background.

	Years of working experience on MEP	Years of practical experience on the jobsite	Domain knowledge
Reviewer A	16 years	13 years	Working experience on lab, market, multiple dwelling, and office building
Reviewer B	12 years	12 years	Working experience on market, office building, factory, and multiple dwelling
Reviewer C	10 years	1 year	Fire protection technician

Table 11
Expert opinion.

Component	Expert opinion
A-D 	Reviewer A: 2 in. pipe can be divided into the other component (avoiding collision) Reviewer B: 2 in. pipe, with enough structural strength, doesn't become displacement and doesn't need to be divided Reviewer C: 2 in. pipe, with enough structure strength and small occupation space, doesn't need to be divided
B 	Reviewer A: No special opinion, decomposition is not necessary Reviewer B: Component, too long and not easy for transporting due to the joint valve; can be divided using a flange valve or weld bond between the 6 meter pipe run and elbow Reviewer C: Be alerted that component B is too long and jointed with one valve which can affect transportability
C 	Reviewer A: No special opinion, decomposition is not necessary Reviewer B: Component C can be further decomposed at the flange valve Reviewer C: No special opinion, decomposition is not necessary

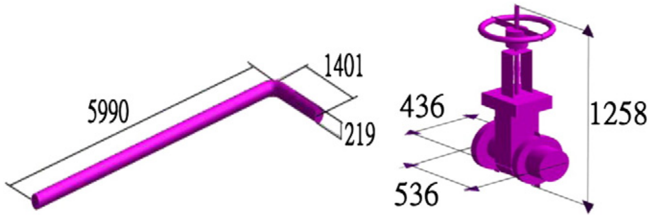


Fig. 44. Decomposition of component B.

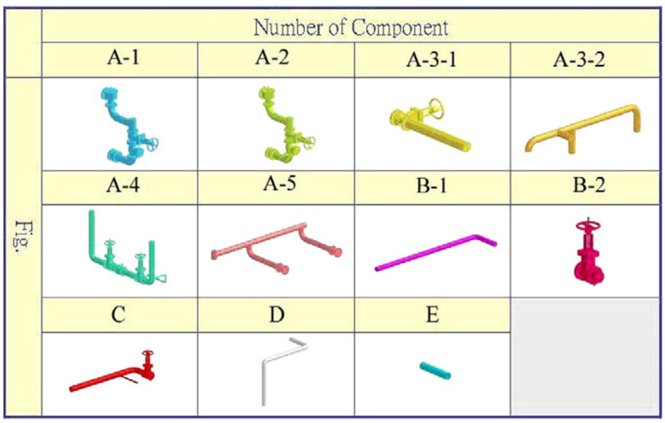


Fig. 45. System decomposition.

After decomposing component B, the system is divided into 11 components and elements and is shown in Fig. 45. The system decomposition is drawn and shown in Fig. 46 with a part of real system is shown in Fig. 47.

4.3.4. Decomposition Validation

Comparing the actual work records with traditional construction method estimate by three experts, the cost variance between prefabricated method and traditional method is shown in Table 12.

Elements are usually outside the MEP room in traditional method and be moved and cut when need, thus it needs to transport elements more times. Elements are packaged into fewer components using the prefabricated methods thus making it more efficient to transport these materials into the room. In transporting cost, prefabricated method saves $784 USD.

Due to the fewer operations to connect the components in the room, prefabricated method needs less temporary hoisting, assembly and welding, the new method saves $3804 USD in temporary hoisting cost, $11,929 USD in assembly cost and $3049 USD in safety and sanitation cost. The total cost what the new method saves is $19,566 USD (refer to Table 12).

In time variance, pipe installation is usually after equipments on site in traditional method, then workers start to cut and connect the pipe elements, but in prefabricated method, because the elements are prefabricated into components in advance and there are fewer operations to connect and transport the components need to be done after equipments on site, it can save time from assembly and welding. In this case, the new method saves 12 days while the original schedule is 14 days (refer to Fig. 48).

5. Conclusion

In this paper a new construction method has been described for efficient componentization of MEP systems using decomposition rules identified in it. After a MEP system has been selected, the first two steps involve establishing an element database and removing equipment from the piping configuration. The feasibility of construction is judged by comparing the attributes of each component such as its weight, location and capacity length to the defined constraints. Constructability issues are considered by analyzing the division location and suitable connection methods.

As seen in the case study, the numbers of weld bonds or flange connections need to be done in the MEP room were decreased substantially (from 111 to only 18) and most of the necessary connections can be prefabricated in a pipe welding shop. Due to the fewer operations in the MEP room, the available construction space for performing the work increases, the cost has been saved to $19,566 USD and time has been saved to 12 days while traditional method needs $66,030 USD and 14 days.

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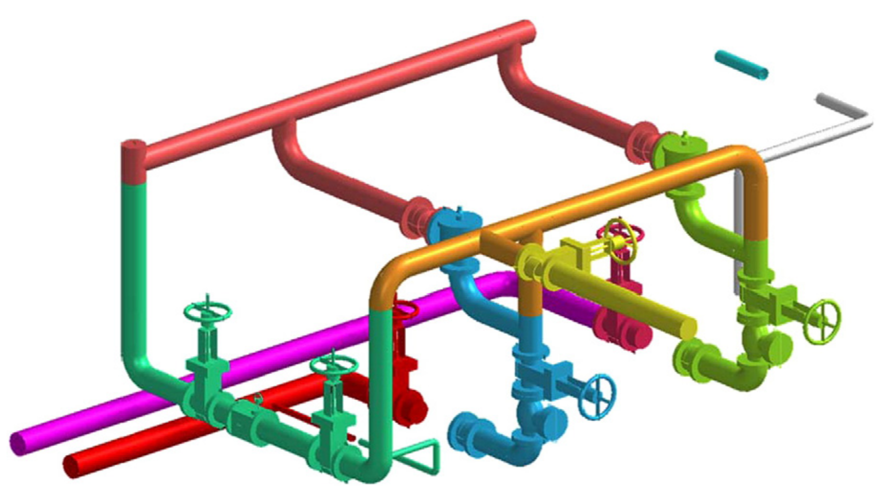

Fig. 46. Results of system decomposition.

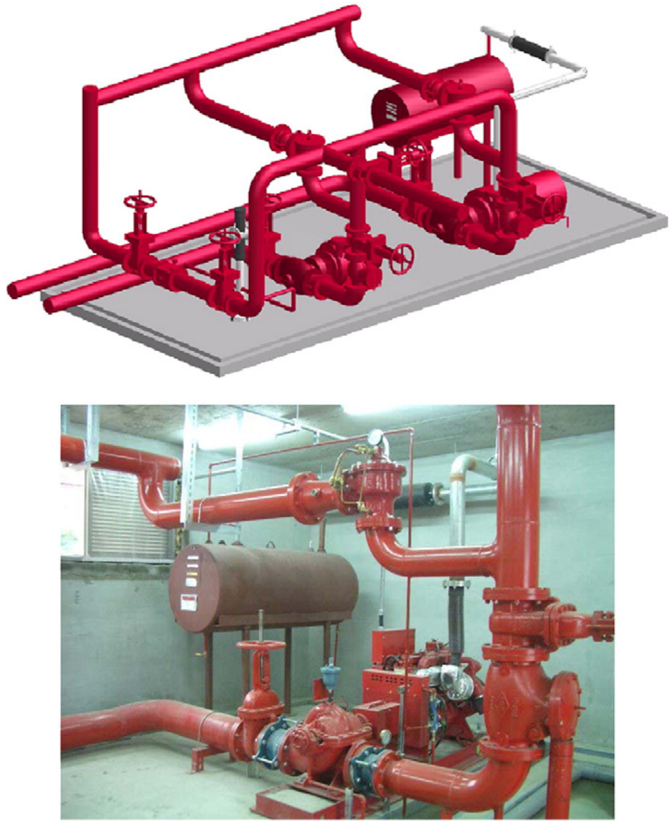

Fig. 47. Real system.

Table 12
Cost variance between prefabricated method and traditional method.

	Prefabricated method	Traditional method	Variance (prefabricate-traditional)
Transporting	535	1320	−784
Temporary hoisting	1444	5248	−3804
Assembly	32,453	44,382	−11,929
Safety and sanitation	12,031	15,080	−3049
Total	46,463	66,030	−19,566

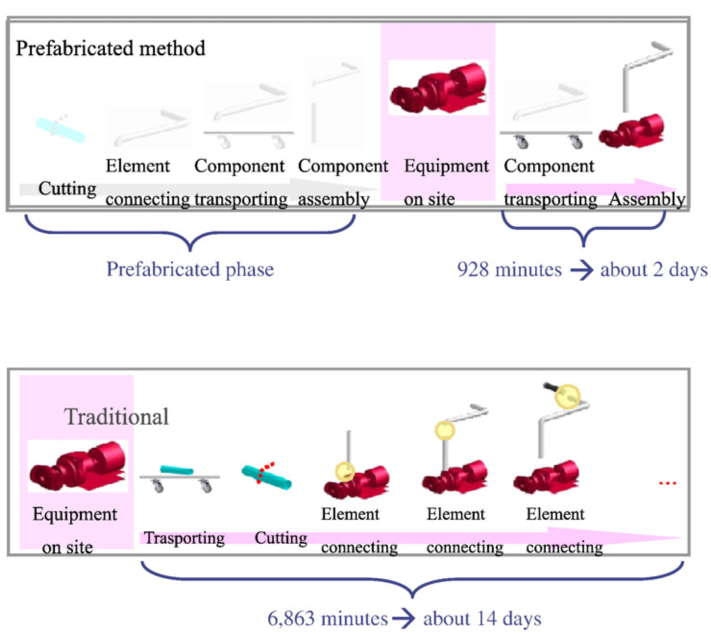

Fig. 48. Time variance between prefabricated method and traditional method.

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