Development and improvement of labor productivity assessment system in construction site by using Information Technology

Takashi Goso, Kohei Imoto
Kochi University of Technology

***ABSTRACT*:** Data collection and analysis for the labor productivity in Japanese construction industry are still done by each site engineer as their personal data. Method of data collection and analysis was already established in 1980's (Work Sampling method). However, this kind of method has not been used organizationally in Japanese construction industry. Personal data will not be stock in each organization. Organizational data collection and analysis is necessary for their productivity improvement activity. Based on productivity data collection, engineers can see quantitative result of their productivity improvement activity. To solve above problem, prototype of labor productivity assessment system was developed in previous study. By the result of this study, automation of labor productivity assessment system has been possible to realize. This system is structured from the following components.
(1)Collecting location data of each working labor (By using ZigBee network system)(2)Collecting acceleration data of each working labor (By using accelerations sensor)(3)Integration of location data and acceleration data (Software was developed) (4)Distinction of productivity classification (Algorism was developed). By using above system, productivity of actual construction site was collected. This system will be continuous improved.

KEYWORDS: productivity data,ZigBee, Acceleration sensor

1. INTRODUCTION

Productivity datais the key for total management of quality, cost and timeof construction project.So, productivity data collection/assessmentis essential matter to execute construction project. However, productivity data collection of Japanese construction site is done by each site engineer as their personal activity. So, reliability of these data is limited for assessment.

Recently, "market price"-based cost estimation system is tried to use for public works in Japan. However, importance of productivity data collection /assessment is not to be decreased. Because site condition of construction works are different each other. In such situation, productivity data is required to set up reasonable construction planningand unit price. Furthermore, productivity data collection and assessment is indispensable for project management such as evidence-based contract administration and productivity improvement activity etc.

Receiving accurate information of labor activity, equipmentusage and material consumption is the basis of productivity data collection /assessment. As 1st step of this study, authors tried to establish and improvethe data collection /assessment system for labor activity. This paper reports process of establish this system.

2. Present situation of labor productivity assessment system in construction industry

2.1 Using Work Sampling Method for construction industry

At the beginning of Work Sampling Method was established, this method has mainly been used for manufacturing industry. From 1980's, this method was began to use for constructionindustry in US. Also, data sampling standard was established by ArchitecturalInstitute of Japan (AIJ) in 1986.

Basic way of these data sampling method has common point as follow.

- Researchers watch labors activityin construction site. Their activities areclassified as "1: Direct Works", "2: Supporting Works" and "3: Delay Activity" for productivity.
- Total time ratio of each classified labor activity will besummarized. If ratio of "2: Supporting Works" or "3: Delay Activity" have large ratio, cause of situation and countermeasure for improving productivity should be found out.

As above, basic way of productivity data collection/assessment has already been established in construction industry.

2.2 Productivity data collection/assessment system by using advanced IT

However, as stated in introduction, this kind of productivity data is collected by each site engineer as their personal activity. Productivity data collection /assessment technology such as work sampling method is thought not to be used organizationally. Personal data will not be stocked in each organization. Moreover, accuracy improvement of productivity data and productivity improvement activity will be realized by organizational data collection/assessment.

Using Information Technology (IT) has advantages for productivity data collection/assessment and continuousproductivity improvement activity as follow.

- Data collection can be collected regularly
- Accurate data collection is regularly
- Productivity assessmentcan be done automatically by using collected electrical productivity data
- Saving effort for data collection

By rapid developing of IT in 1990's, any industries introduce IT for their works. Also, construction industry has been installed IT for their works. For example, Radio Frequency Identification(RFID) hasbeen used for gate control of labor, equipment and material in construction site.

The other hand, productivity data collection/assessment system by using advanced IT has not been established yet.This study tried to establish productivity data collection/assessment systemcomposed by wireless communication technology and acceleration sensor to find out labor location and activity data in construction site.

3. Establishing productivity data collection/assessment system

Productivity data which was received in this system should be useable not only accuracy improvement of cost estimation but also project management such as evidence-based contract administration and productivity improvement activityetc., as stated in introduction. Figure 1 shows the whole system thatauthors try to establish.

Resources of construction work are labor, equipment and material. As 1st step, the data collection/assessment system for labor activity is trying to establish in this study..

Study flow from the "I. Activity of Labor/Equipment(L/E)" on 2nd line to the "Accurate

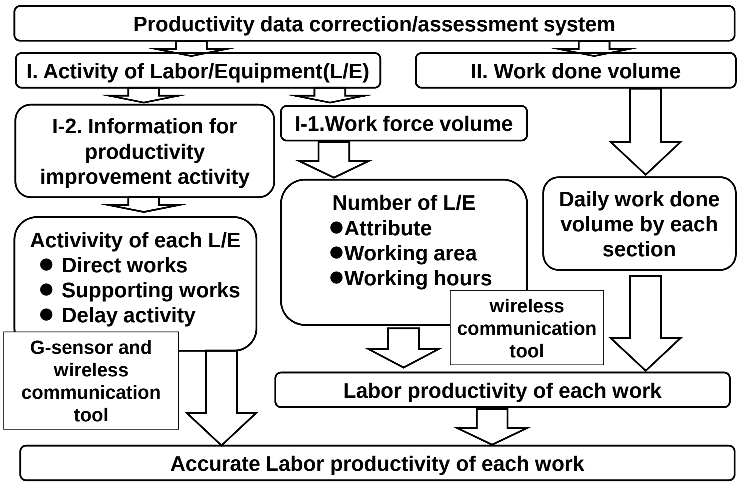


Figure 1 the whole system of productivity data collection/assessment

Table 1 activity classification for productivity assessment

1. Direct Works	
2. Suppoting Works	2-1. Read Plans/Instruction
	2-2. Travel
	2-3. Transportation
	2-4. Tool/Materials
3. Delay Activity	3-1. Late Start/Early Quit
	3-2. Waiting
	3-3. Personal
	3-4. Break

Labor productivity of each work" on last line of figure 1 shows the same way of common Work Sampling Method. This paper reports establish process of automated Work Sampling system by using advanced IT. Flow from the "II. Work done volume" is not included in this paper.

3.1Activity classification for productivity assessment

This system can receive data of each labor activity such as"what work he did?" and "How long did he do the work". This kind of data is stocked as the dataof Work Force Volume. Actual productivity can be found out as thequotient of the Work Force Volume divided by Actual Work Done Volume.

The other hand, essential productivity data is required to be avoidedunnecessary activity which does not contribute to productivity. So,information of **"**How did he do the work"should be received by this system. To solve this problem, activity classification for productivity assessment was set up as table 1. This classification categorizes working situation as "Do his work contribute to productivitydirectory?", "Did he travel to change work area?", "Did he transport tool or material?", "Did he read plan or specification?", "Did he stop his work by personal reasons?" etc.

3.2 Summary of productivity data collection /assessment system

Policy of establishment of this system is as follow

- Work force volume of 1 unit works (ex. 10m^3) will be collected as productivity data.
- Productivity data will be collected and analyzed by each type of job (ex. Form builder, Rebar Worker, Navvy, etc.) and revel of workers (Foreman, skilled labor, unskilled labor, etc.). Productivity of each labor does not be analyzed.
- Small electrical device will be put on each worker. Labor activity will be received from site office onreal-time.

Figure 2 shows information flow of the productivity data collection/assessment system established as above policy. Data collection and assessment is done as follow.

- Transmitter (ex. T-01: put of worker) connect the nearest Receiver (ex. R-02: installed in construction site)
- Data receiving time, transmitter ID(ex. T-01), receiver ID(ex. R-01) and acceleration data is integrated by PC in site office.
- Location of each worker is shown in PC screen.
- Type of job and transmitter ID of each worker are integrated to other data
- By above data, labor's activity is classified as table 1

To realize this system, following matters are required and developing in this study.

- Transmitter and receiver
- Indication system of laborslocation act on

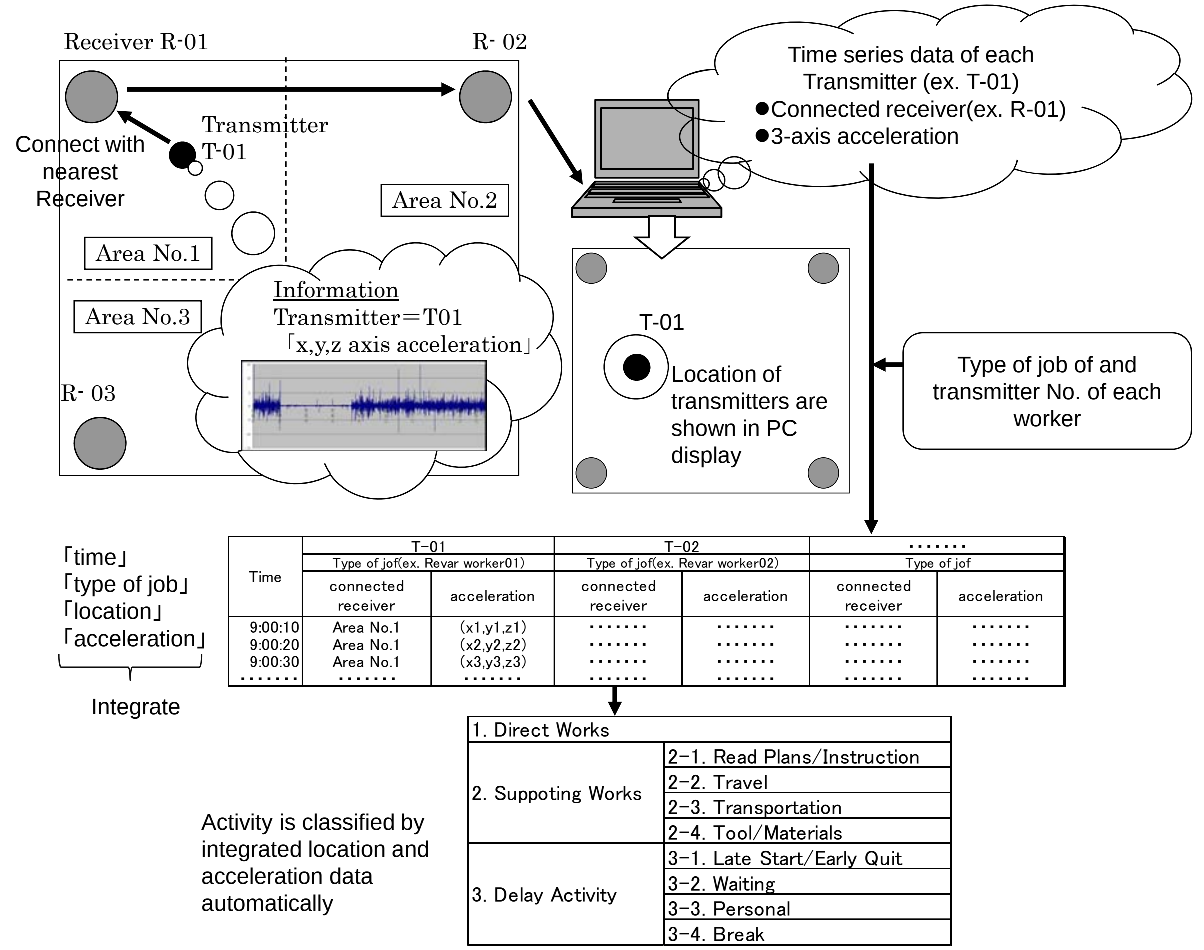


Figure 2Informationflow of the productivity data collection/assessment system

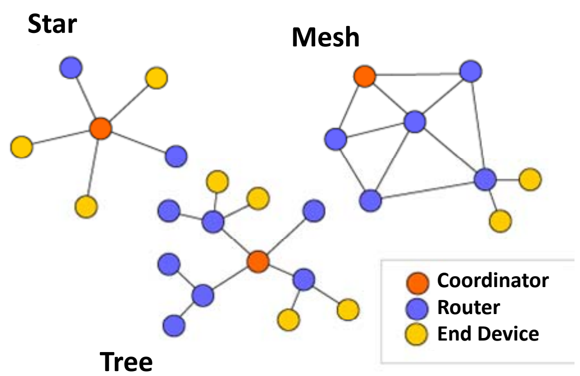


Figure 3"Relay Communication" of ZigBee

PCwhich is based on connection information between transmitter and receiver.

- Automatic activity classification system which is integrated bylabor's location and acceleration data

3.3 Work force volume data collection system

At the beginning of this study, RFID was used to establish this system to apply underground or indoors site. However, following problems were remained.

- Miniaturize receiver antenna
- High quality wireless communication in construction site with many obstacles (material, equipment, structure etc.)

To solve above problem, "ZigBee" communication standard are selected to re-establish this system. ZigBee is one of the standard wireless communication systems. "Zig"meanszigzag, and "Bee"means the insect. ZigBee is composed from "Coordinator", "Router" and "End Device". Coordinator is connected to PC and act as controller for wireless connection of all Routers and End Devices.

ZigBee can realize "Relay Communication" as shown figure 3. This "Relay Communication" function is advantage to apply for construction site with many obstacles.

Each ZigBee devices measure electric wave

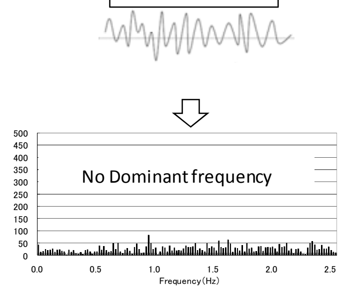
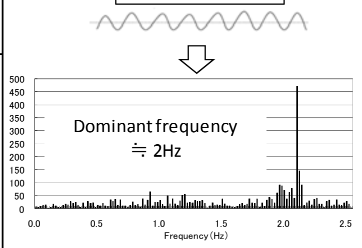
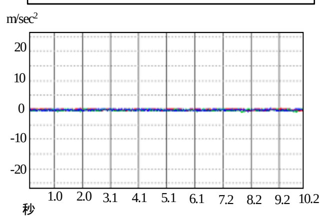
Activity classification		Acceleration sensor: Wave pattern	Acceleration sensor: Acceleration	ZigBee: Location	ZigBee: Time
1. Direct Works		irregular wave 	Av.g: over 1m/s^2 or MAx: over 2m/s^2	Work area (construction site)	Normal working time
2. Suppoting Works	2-1. Read Plans/Instruction	No Dominant frequency	Avg: under1m/s^2 and Max: under 2m/s^2		
	2-2. Travel	regular wave 	Avg: under 5m/s^2	anywhere	anytime
	2-3. Transportation	Dominant frequency ≒ 2Hz	Avg: over 5m/s^2	Work area (construction site)	Normal working time
	2-4. Tool/Materials	irregular wave	Avg: over 1m/s^2 or Max: over 2m/s^2	Tool box /Material yard	
3. Delay Activity	3-1. Late Start/Early Quit	Very small wave (≒0) 		Not Work Area (Site office etc.)	Normal working time (Just before/after break time)
	3-2. Waiting			Work area (construction site)	Normal working time
	3-3. Personal (Personal)			Not Work Area (Site office etc.)	
	3-4. Break				break time

Figure 4 Prototype of criterion to find out labor activity classification

quality (LQI: Link Quality Indicator), and wireless connection are realized between biggest LQI devices. This function is usable to realize labor location finding system. This communication standard is now spreading in the world. So, cost of devices is expected to beinexpensive.

3.4 Data collection system for productivity improvement activity

To realize"I-2.Information for productivity improvement activity" of Figure 1, labor activity information should be received. Labor activity information is found out by total analysis of acceleration, location, working time and job of each labor.

Prototype of criterion to find out labor activity classification was set up as Figure 4 based on previous research and operating test of acceleration sensor.

Dominant frequency distinguishes difference of "irregular wave" and "regular wave" on Figure 4. Waking action makes about 2 steps per second. So, if 2Hz of, labor activity is classified "2-2 Travel" or "2-3 Transportation". If 2Hz of dominant frequencyis not found out, labor activity is classified "1. Direct Works" or "2-1 Read Plans/Instruction"

4. Accuracy improvementof productivity data collection/assessment system

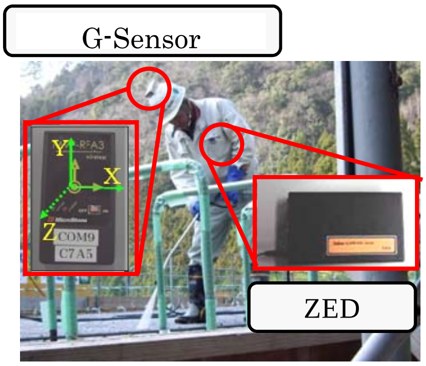


Figure 5End Device and accelerationsensor

Figure 6ZigBeeCoordinator and Reuters on construction site

4.1 Confirmation of practicality of prototype system

To confirm practicality of prototype productivity data collection/assessment system, location and acceleration data of laborswerecollected automatically in real construction site (Automated sampling).ZinBee End Device and accelerationsensorwere put on 5 labors as shown Figure 5. Furthermore, ZigBeeCoordinator was put on site office, and ZigBee Reuters were put on construction site as shown Figure 6.

Work sampling by researchers (Manual sampling) was done with automated data sampling. Result of manual sampling was compared with the automated sampling.

Figure 7 shows the part of result of manual samplingand automated sampling.

For example, “3.4 Break”is shown in 15:06-15:30 as the result of manual sampling. The other hand, accelerationof same time is nearly 0(m/s^2) and location is site office. Furthermore, this time is set as break time. So, result of automated sampling is also “3.4 Break”.

“1.Direct Works” is shown in 14:57-15:00 as the result of manual sampling. The other hand, acceleration of same time is larger than 2(m/s^2) and wave pattern is irregular. Furthermore, location is construction site and this time is set as working time. Thus result of automated sampling is also “1.Direct Works”.

“2.2 Travel” is shown in 15:03-15:06 as the result of manual sampling. The other hand, acceleration of same time islarger than 2(m/s^2) and dominant frequency can be find out around 2Hz. Thus result of automated sampling is also “2.2 Travel”.

Result of manual sampling and automated sampling is different in 15:30-15:33. “2.2 Travel” received by automated sampling is thought to be right, because labor may walk from site office to construction site.

“3.3 personal” is shown in 15:57-16:03 as the result of manual sampling. Labor is stayed in toilet near site office at that time. The other hand, acceleration of same time is nearly 0(m/s^2) and location is site office. Furthermore this time is set as working time. Thus result of automated sampling is also “3.3 personal”.

As above, this prototype is generally thought to be practical.

4.2 Accuracy improvement of this system

This prototype system was continuously improved with data collectionexperiment in construction sites. Assessment procedure (ex. threshold value of acceleration, dominant frequency finding system, distinction flow for classification of activity, and etc.) is also upgrading.

Table 2 shows accuracy of present productivity assessment system received from other siteexperimentation. “1. Direct Works” and “3.4 Break” are almost accurate. However, other productivity activity classification could not receive

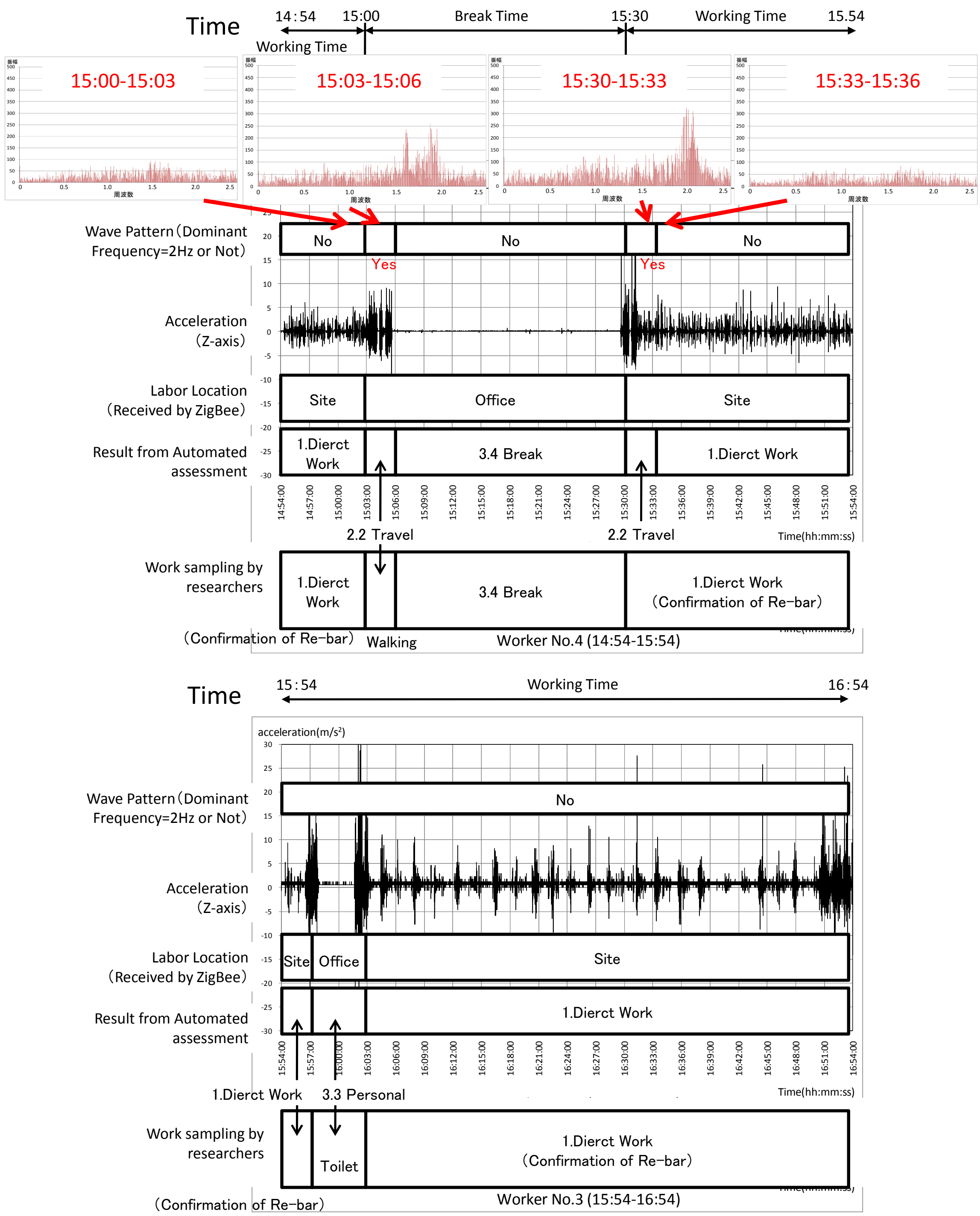


Figure 7Part of result of manual sampling and automated sampling

so accurate. Authors are trying to develop more accurate assessment procedure.

4.3 Developing new data collection device

For more effective data collection, new devices which integrated ZigBee wireless communication system and acceleration sensor were established. Figure 8 shows the new device. New devices are much smaller than old one.

5. Conclusion

This labor productivity assessment system has room for improvement, and this study is now ongoing. High-reliable productivity data will be expected to receive by futuresystem. This is the first step to realize “Process Control” of construction project in Japan.

Table 2Accuracy of present productivity assessment system

	Automated sampling									Total	Accuracy
Manual sampling	1.1	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4		
1.Directwork	360	2	19	0	0	0	0	0	0	381	94%
2.1Read /Instruction	15	2	4	0	0	0	0	0	0	21	10%
2.2Travel	27	1	21	0	0	0	0	0	0	49	43%
2.3Transportation	75	0	24	0	0	0	0	0	0	99	0%
2.4Tools /Materials	7	0	1	0	12	0	0	0	0	20	60%
3.1Early Quit/Late Start	3	0	0	0	0	8	0	3	0	14	57%
3.2Waiting	2	0	0	0	0	0	0	0	0	2	0%
3.3Personal	2	0	0	0	0	0	0	3	0	5	60%
3.4Break	6	0	3	0	0	0	0	0	82	91	90%

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Figure 8New devices which integrated ZigBee wireless communication system and acceleration sensor