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Physiological Workload of Chainsaw Felling and Processing Workers – Case Study

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ABSTRACT

Chainsaw felling and processing work is conducted in various natural conditions and requires significant physical effort from the workers, movement in severe weather and environmental conditions, and has a high risk of injury. The aim of this study was to determine the physiological workload of chainsaw operators through continuous heart rate measurement during the entire working day. The research was carried out during the summer of 2024, encompassing different parts of the Federation of Bosnia and Herzegovina. Heart rate was measured using a Polar H10 Heart Rate Monitor Chest Strap with continuous data logging and storage of heart rate readings. A time study was performed based on recordings conducted simultaneously with the recording of heart rate, with the aim of determining the duration of individual work operations and identifying the work operation with the highest negative impact on the worker. The average working heart rate during productive work time for subject 1 was 104 bpm, 83 bpm for subject 2, 109 bpm for subject 3, 94 bpm for subject 4 and 129 bpm for subject 5. The results of the Kruskal-Wallis test showed a statistically significant difference in average heart rate in relation to the time study element. The heart rate reserve (%HRR) for the whole study time was estimated at 41.05 % for subject 1; 22.69% for subject 2; 44.50% for subject 3; 24.04% for subject 4, and 45.78% for subject 5. The results of the study showed that the %HRR of chainsaw operators during felling and processing exceeded the value of 40% for 3 out of 5 subjects, which corresponds to hard work and may have negative consequences for operators´ health.

Keywords: ergonomy; Federation of Bosnia and Herzegovina; forest harvesting; heart rate reserve; chainsaw operator

INTRODUCTION

Based on data from the Federal Ministry of Agriculture, Water Management and Forestry (2021), the Federation of Bosnia and Herzegovina´s (FBiH) total forest and forest land area is 1,518,466 hectares, of which 1,241,336.1 hectares are state-owned. According to the Information on Forest Management in the FBiH in 2021, 40% of the state forests of the FBiH are high forests with natural regeneration, which constitute the basis of forest production. The forests of Bosnia and Herzegovina are identified as a major ecological and economic resources (Musić et al. 2013).

Logging in Bosnia and Herzegovina is mainly conducted through a combination of manual and mechanised work, felling and production of forest wood assortments are done motor-manually with chainsaws and extraction is mostly handled by tractors (Sokolović and Musić 2009, Halilović et al. 2015, Knežević et al. 2017). Work operations within the tree felling and wood processing phase are conducted in various terrain and stand conditions and require significant physical effort from the workers. The workload of workers in forest exploitation represents a complex combination of physical effort, movement in severe weather and environmental conditions, and a high risk of injury. Consequently, the profession of forestry workers is defined as very dangerous, with a high rate of injuries and work-related diseases during their working life (Çalışkan and Çağlar 2010, Šporčić et al. 2015, Bačić et al.

2020, Halilović et al. 2021, Masci et al. 2022, Ljuboš et al. 2023, Landekić et al. 2023, Staněk and Mergl 2024).

The physical workload of forestry workers can be determined based on heart rate measurements (Grzywiński et al. 2017). Heart rate during work represents the average pulse value for the entire working day, including breaks (Kirk and Sullman 2001). The maximum heart rate serves as a standard indicator of the highest acceptable individual effort in work physiology **(**Masci et al. 2021, Sammito et al. 2024). Variations in heart rate during work are directly proportional to the intensity and duration of the task (Martinić et al. 2006). Determining physical workload based on heart rate is a commonly used method for research in forestry because of its practicality (Melemez and Tunay 2010a, Eroglu et al. 2015, Grzywiński et al. 2017, Tsioras et al. 2022, Poje et al. 2024, Abramuszkinová Pavlíková et al. 2024, Okuda et al. 2025).

Melemez and Tunay (2010b) found that the average physiological workload of loading machine operators during forestry work was 49%, which corresponds to medium-heavy work. Cheţa et al. (2018) evaluated the ergonomic working conditions in flatland poplar forests, and the results indicate a heavy load during the productive time. Halilović et al. (2021) cited that the heart rate reserve (%HRR) of chainsaw operators during tree felling and processing exceeded the value of 40%, which is classified as heavy work. Masci et al. (2022) determined that the most demanding work task was tree felling, which requires a higher level of cardiac load and longer periods where the worker is in an awkward working posture. Grzywiński et al. (2022) examined physiological workload during logging operations depending on the season (summer-winter), and concluded that heart rate indices and energy expenditure values were higher in winter than in summer. Pavliková et al. (2024) in their study were focused on analysing the impact of the weight of the work tool, and the results proved that using a lightweight work tool contributes to the decrease in heart rate and reduces the time a worker spends in a non-ergonomic working position. Poje et al. (2024) found that the physiological workload was lower when using a battery-powered chainsaw than a petrol-powered chainsaw. Okuda et al. (2025) concluded that the workload in forestry operations cannot be interpreted comprehensively due to the diversity of work operations, insufficient information about measurement conditions, and limited sample sizes. Consequently, the authors suggest a more detailed analysis focusing on workers' environment, working conditions, measurement and work periods, and break times.

The complexity and significance of forest felling and processing, alongside a domestic research gap, highlights the need for further studies. This study aims to determine the physiological workload of chainsaw operators through continuous heart rate measurement during the entire working day, identifying the work operation with the highest negative impact on the worker.

MATERIALS AND METHODS

The research was carried out during the summer of 2024, encompassing different parts of the Federation of Bosnia and Herzegovina, including Una-Sana Canton (Cantonal Public Enterprise “Unsko-sanske šume“ Ltd. Bosanska Krupa), Tuzla Canton (Cantonal Public Enterprise “Šume Tuzlanskog kantona“ Ltd. Kladanj), Bosnian-Podrinje Canton (Cantonal Public Enterprise “Bosansko-podrinjske šume“ Ltd. Goražde) and Zenica-Doboj Canton (Cantonal Public Enterprise “Šume Zeničko-dobojskog kantona“ Ltd. Zavidovićima) (Figure 1).

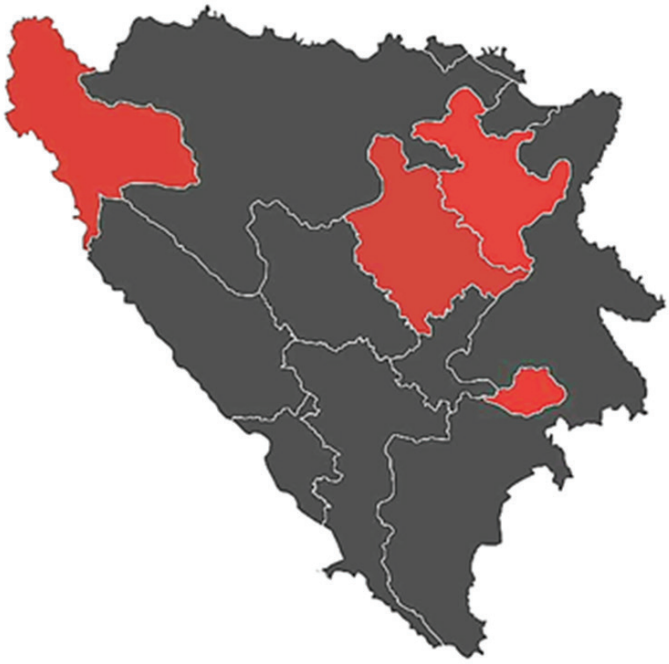

Figure 1. The location of the study area.

The workers were selected based on their consistent productivity over a prolonged period. The focus was on those demonstrating average or standard levels of effort, deliberately excluding both outliers with extreme output and those with suboptimal results. The study was conducted with the prior authorisation and full cooperation of each forestry enterprise involved. Additionally, each worker provided their explicit consent to be part of the study, following a clear explanation of the research objectives. A total of 5 chainsaw workers were sampled in different areas (Table 1). The trees were felled and processed into wood assortments with Husqvarna 372 XP and Stihl MS 382 chainsaws. Anthropometric characteristics of the chainsaw workers are shown in Table 2.

Heart rate was measured using a Polar H10 Heart Rate Monitor Chest Strap with continuous data logging and storage of heart rate readings (Figure 2). The measurements were carried out during productive work time and delays. Simultaneously with the pulse recording of the chainsaw operator, a work and time study was conducted with the aim of determining the duration of individual work operations during tree felling and processing. Recorded heart rate data was downloaded via Polar Beat App and sorted out in MS Excel 2021. Statistical analyses were carried out using the Statgraphics Centurion XVI software. Productive work time was divided into work operations, as shown in Table 3.

Table 1. Terrain characteristics of the study area.

Compartment	Forest enterprise	Average elevation (m)	Slope (°)	Terrain topography	Exposure
1	FTK	320-630	15-25	valley and basin	N; NW
2	FTK	400-650	18-20	valley and basin	NE-N; NW-W
3	BPF	770-1120	10-30	steep downhill	N; NW
4	BPF	770-1121	10-30	steep downhill	N; NW
5	USF	800-950	10	slightly downhill	E

Table 2. Anthropometric characteristics of the chainsaw workers.

Subject	Age (years)	Weight (kg)	Height (cm)	Work experience (years)	HRrest (bpm)	HRmax (bpm)	BMI ($kg \cdot m^{-2}$)
1	47	102	185	16	63	173	29.80
2	46	85	184	15	53	174	25.11
3	53	80	189	20	74	167	22.40
4	52	72	168	14	61	168	25.51
5	28	110	184	10	77	192	32.49

Table 3. Time study elements.

	Time study element	Descriptions of effective work time and delays
Productive time	Preparatory-final time	Taking of work orders, chainsaw preparation, cleaning and service maintenance
	Moving to felling site	Walking from landing site to felling site
	Moving	Walking from felled and processed tree to another marked tree
	Felling	Preparing of workplace, choosing of felling direction and tree felling
	Delimbing and processing	Cutting of branches from stem and processing of wood assortment by chainsaw horizontal cut
	Bucking the fuelwood	Cutting log into shorter lengths (fuelwood or other purposes)
	Moving to landing site	Walking from felling site to landing site
Delays		Personal delay (meal time, resting)
		Equipment servicing (service of chainsaw and chainsaw bar by operator)
		Technical delay (malfunctions and their removal)
		Organizational delay (planning, field survey)
		Delay due to adverse weather conditions
		Other delays

Relative heart rate at work was obtained using following formula:

$$\%HRR = \frac{(HR_w - HR_r)}{(HR_{max} - HR_r)} \times 100$$

where HR_w is the average working heart rate, HR_r is the resting heart rate, and HR_{max} is the maximum heart rate (Vitalis 1987).

The maximum heart rate is different between workers and decreases with ageing. The most common formula for its estimation is:

$$HR_{max} = 220 - age \text{ (Rodahl 1989).}$$

The minimum measured heart rate value for the whole working day was taken as the resting heart rate (Sammito et al. 2024). Classification of the physiological workload was done by following the scale in Table 4.

Table 4. Grading the physiological workload (Apud et al. 1989).

Physiological workload	Average heart rate (bpm)
Very low	<75
Low	75 - 100
Moderate	100 - 125
High	125 - 150
Very high	150 - 175
Extremely high	>175

Figure 2. Polar H10 Heart Rate Monitor Chest Strap.

RESULTS

The operational data and harvesting statistics are summarised in Table 5. A total of 102 trees were harvested over a period of 15 working days. The species composition of the harvested timber primarily consisted of European Beech and other broadleaf species. Initial analysis of the harvesting data indicates a total wood volume of 156.17 m3, with a daily output that varied across the different forest compartments.

The average working heart rates, during productive work time, that reached the highest value are for subject 3 (121-140 bpm) and subject 5 (95-123 bpm). The minimum average working heart rates is for subject 2 (62-92 bpm). A detailed overview of the statistical results and workload indicators is provided in Table A1. The minimum heart rate for the whole study was recorded during the preparatory-final time, 62 bpm (subject 2), and the maximum heart rate recorded during equipment servicing, 146 bpm (subject 3). Time study elements, such as dealing with hung-up trees, bucking the fuelwood, equipment servicing and moving to the landing and felling site, were among those with the highest value of heart rate reserve (%HRR). The minimum %HRR was during the preparatory-final time (7.24%). %HRR for the whole study time was 41.05 % for subject 1, 22.69% for subject 2; 44.50% for subject 3; 24.04% for subject 4 and 45.78% for subject 5. According to Apud at al. (1989) physiological workload for subject 1 was low to moderate depending on time study element, for subject 2 every time study element was low, for subject 3 most of the time study element was moderate except equipment servicing (146 bpm), for subject 4 every time study element was low except personal delay (71 bpm) and for subject 5 most of time study elements was high (Figure 3).

Different letters show significant differences among time study elements according to post hock Tukey´s test

The non-parametric Kruskal-Wallis test was used to determine the differences between the average heart rates for various time study elements (Table 6)**.** Post hoc cross-comparisons between average heart rates were performed using Tukey´s test. Results showed a statistically significant difference in average heart rate in relation to the time study element (p=0.0000).

DISCUSSION

The average working heart rates for productive time for subjects 2 and 4 are 83 and 94 bpm, respectively. This discrepancy for subject 2 can be because of easier working conditions despite high productivity, whereas for subject 4, the lower values were likely the results of a reduced workload, which mitigated the physiological impact of the more demanding working conditions. Poje et al. (2024) in a study on the effects of using petrol and battery-powered chainsaws reported higher values, 90.4 bpm and 86.9 bpm. The average working heart rates determined for subjects 1 and 3 (104 and 109 bpm) are similar to the range (108-116 bpm) cited by Martinić (1995). The average working heart rate for subject 5 is 129 bpm, which is similar to the winter-time results determined by Grzywinski (2022) and Masci et

Table 5. Timber harvesting and operational data.

Subject	Volume of processed wood assortments (m^3)	Work duration (days)	Number of felled trees	Tree species
1	36.57	5	32	European Beech and other broadleaf species
2	44.30	3	23	European Beech and other broadleaf species
3	37.98	3	22	European Beech and other broadleaf species
4	17.55	2	13	European Beech and other broadleaf species
5	15.97	2	10	European Beech
	3.80		2	Silver Fir

Table 6. Results of Kruskal-Wallis test.

Time study element	Average heart rate (bpm)				
	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Preparatory-final time	96h	62g	95f	81e	139a
Moving to felling site	100f,g	68f	95f	-	-
Moving from tree to another tree	109e	87b	111e	89c	122e
Felling	114c,d	86b,c	111e	92b	121e
Delimbing and processing	115c,d	86c	111e	97a	130c
Bucking the fuelwood	118b	92a	113d	92b	129c
Moving to landing site	93j	88b	123c	98a	140a
Personal delay	94i	82d	127b	71g	133b
Equipment servicing	100f,g	72e	146a	75f	126d
Technical delay	100f,g	72e	-	85d	122d,e
Organizational delay	81k	82d	124b,c	-	136a,b
Other delay	121a	89a,b	-	-	-
Rest time	63l	-	-	-	-
Kruskal-Wallis p value	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*

*Denotes statistically significant difference according to Kruskal-Wallis test

al. (2022). Çalişkan & Çağlar (2010) found a mean working heart rate of 122.8 bpm, which is in line with findings of this study and specifically those of subject 5. Arman et al. (2021) determined that the average working heart rate was 116.08 bpm, while Melemez and Tunay (2010) reported that heart rates while working were 115±7 bpm. Heart rates are influenced by numerous modifiable and non-modifiable factors, including the test subjects´ living habits, resulting consequences and external conditions (Sammito et al. 2024).

The maximum heart rate values were measured during other delays, which included dealing with hung-up trees (121 bpm), bucking the fuelwood (92 bpm), equipment servicing (146 bpm), moving to the felling site (98 bpm) and moving to the landing site (140 bpm). Masci et al. (2022) found that the mean heart rate during felling was 136.7 bpm, 143.5 bpm during delimbing and 135.63 bpm during bucking. The resting heart rates for all subjects range from 53 to 77 bpm, which aligns with the selected and presented studies in the scoping review by Okuda et al. (2025).

The average physical workloads (%HRR) for subjects 2 and 4 are lower than those presented by other authors. The result for subject 1 is similar to that shown by Memelez and Tunay (2010). The average physical workloads for subjects 3 and 5 are higher than those of others and similar to Çağlar (2021) for debarking, Çalışkan and Çağlar (2010) for forest workers in felling operations, Cheţa et al. (2018) during motor-manual tree felling and processing in poplar clear cuts and Arman et al. (2021) for clearcutting

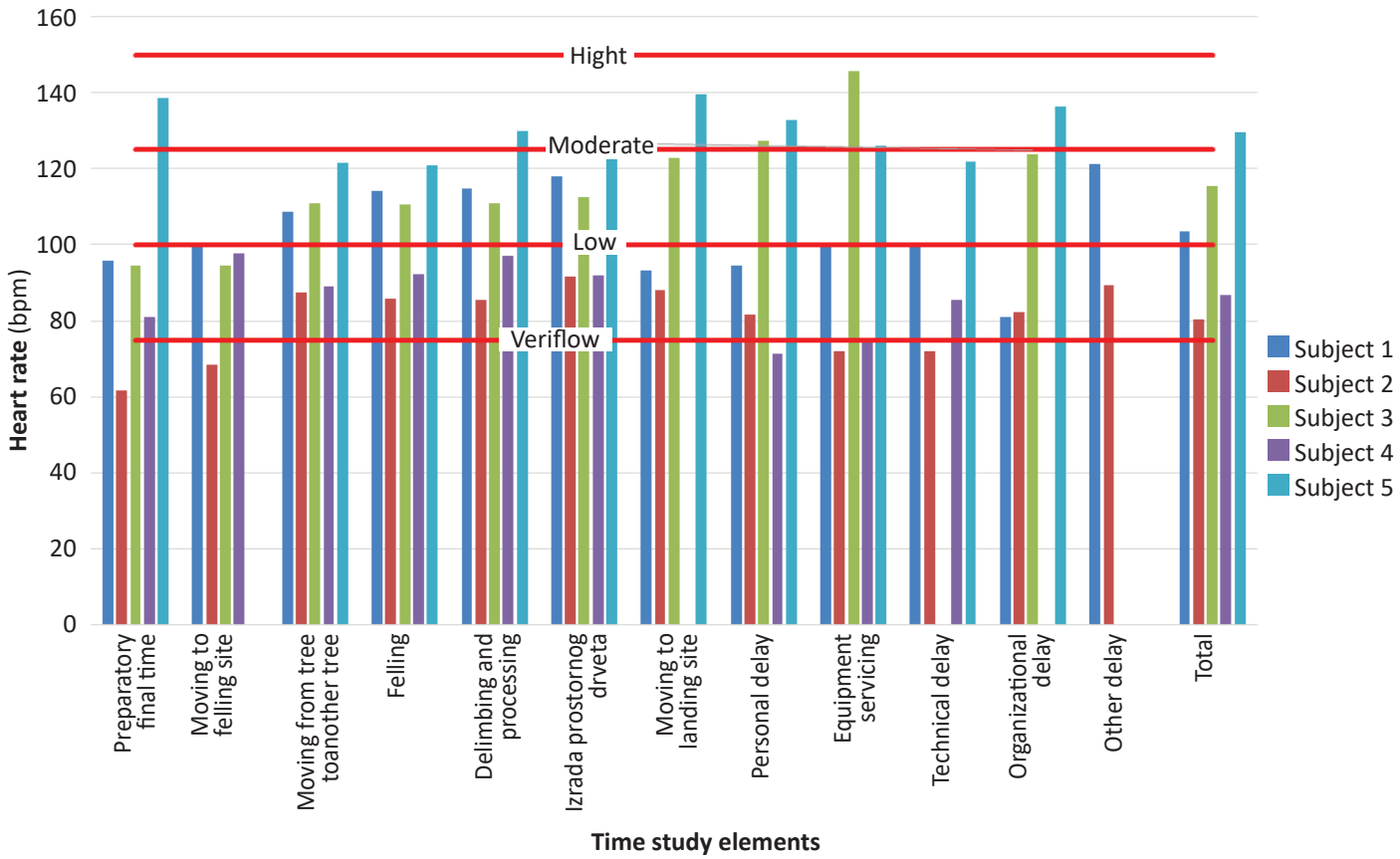

Figure 3. Grading the physiological workload.

operations. Potočnik and Poje (2017) described that the permissible value of heart rate reserve should not exceed value of 40% for all work tasks of effective time and delays.

The highest physiological workload in this study was recorded during equipment servicing (76.97%), dealing with a hung-up tree (56.26%), delimbing and processing (50.65%) and moving to the landing site (54.45%). The lowest physiological workload was measured during the organisational delay (22.05%) for subject 1, preparatory-final time (7.24%) for subject 2, preparatory-final time and moving to felling site (both 22.10%) for subject 3, personal delay (9.63%) for subject 4 and felling (38.15%) for subject 5. Cheţa et al. (2018) found that the lowest physiological workload was during work preparation (21.76%) and the highest was during technical delay (57.49%).

CONCLUSIONS

Motor-manual felling and processing is difficult and dangerous work that puts heavy loads on the operators. The primary objective of this study was to analyse the workload of foresters during the felling and processing phase. The research faced certain limitations, including a small sample size and a lack of interest among some workers. The results of the study showed that the %HRR of chainsaw operators during felling and processing exceeded the value of 40% for 3 out of 5 subjects, which corresponds to hard work and may have negative consequences for operators´ health. The other two operators had the lowest HRR%. This variability could be caused by working conditions, organisational structures, anthropometry and the living habits of the operators. In order to reduce the %HRR and improve productivity, it is necessary to consider measures such as operator training, changes in work organisation, proactive health monitoring and optimised recovery protocols. Future research should be conducted in collaboration with occupational medicine specialists to ensure more precise measurement and interpretation of results. Furthermore, incorporating advanced methods, such as Holter monitoring, would provide deeper insights into the physiological strain on workers.

Author Contributions

VH, JM, JK, AA conceived and designed the research and carried out the field measurements, JK, AK and EP processed the data and performed the statistical analysis, VH supervised the research and helped to draft the manuscript, JK and EP wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Table A1. Descriptive statistics of heart rate per chainsaw worker.

Time study element	Heart rate (bpm)																						
	Subject 1					Subject 2					Subject 3					Subject 4					Subject 5				
	min	max	mean	SD	HRR%	min	max	mean	SD	HRR%	min	max	mean	SD	HRR%	min	max	mean	SD	HRR%	min	max	mean	SD	HRR%
Preparatory-final time	75	132	96	12.12	34.66	55	79	62	4.16	7.24	77	125	95	9.03	22.10	72	104	81	6.22	18.69	120	151	139	8.98	53.56
Moving to felling site	72	151	100	21.09	38.07	53	108	68	12.34	12.63	74	150	95	17.67	22.10	71	138	98	18.96	34.23					
Moving from tree to another tree	82	140	109	13.88	45.37	62	126	87	18.54	28.49	81	166	111	19.80	39.83	63	116	89	13.02	26.06	86	154	122	20.52	38.70
Felling	84	140	114	11.03	50.17	60	123	86	14.11	27.05	79	169	111	17.15	39.39	69	133	92	15.90	29.36	81	161	121	20.25	38.15
Delimbing and processing	86	136	115	9.09	50.65	56	124	86	16.11	26.98	78	177	111	15.64	39.78	65	136	97	13.40	33.64	79	162	130	20.83	45.97
Bucking the fuelwood	91	141	118	10.57	53.30	56	119	92	15.38	31.99	79	178	113	20.78	41.55	65	136	92	13.60	28.97	77	158	129	19.55	45.13
Moving to landing site	75	139	93	12.14	32.32	76	107	88	7.29	28.89	90	158	123	13.69	52.44						113	166	140	8.94	54.45
Productive time	72	151	104	17.62	42.53	53	126	83	16.70	24.79	74	178	109	18.29	37.63	63	138	94	14.52	30.84	77	166	129	19.88	45.22
Personal delay	75	150	94	13.98	33.47	56	129	82	16.71	23.62	87	167	127	21.38	57.32	61	123	71	10.75	9.63	82	159	133	18.66	48.51
Equipment servicing	79	136	100	11.13	38.01	57	117	72	13.36	15.55	125	162	146	9.77	76.97	62	134	75	10.82	12.93	84	165	126	18.29	42.61
Technical delay	82	130	100	13.13	38.21	60	82	72	6.64	15.59						73	131	85	13.62	22.84	88	149	122	18.28	39.10
Organizational delay	63	121	81	8.04	22.05	63	112	82	13.73	24.32	112	132	124	5.06	53.55						98	154	136	18.19	51.61
Other delay	115	129	121	3.08	56.26	79	105	89	7.06	29.94															
Rest time	55	98	63	6.72																					
Total	63	151	103		41.05	53	129	80		22.69	74	178	115		44.50	61	138	87		24.04	77	166	130		45.78

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