The terminal cycle time in road-rail combined transport

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Abstract

The object of this paper is the statistical study of some variables of the cycle of a road-rail intermodal terminal. The variables considered are the total average time of the terminal cycle, relative to the truck vehicle, and the number of vehicles entering the terminal. The study of the variables was carried out at the terminal of Verona, Quadrante Europa. The first part of the paper reports the execution of the surveys, the second regards the calibration of specific statistical models related to the variables.
Keywords: terminal cycle, freight transport, terminal time, trucks, intermodality, logistic.

1 The road-rail combined transport

1.1 The international traffic

The road-rail combined transport has been introduced in Europe for several decades and today it represents an important option for freight.

The combined system uses two or more modes of transport forming a single innovative mode, trying to add the benefits of the two basic modes confining the disutilities.

In the general framework of freight transport on the international land distance, combined transport represents the optimal modality in terms of time and cost for the users and in the terms of energy and sustainability for the collectivity. Then it is one of the main points where can be increase possible to the sustainability, reducing energy consumption in all forms. In combined transport the loading unit (containers, swap body or semi-trailer) reaches the road-rail transfer terminals,

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then it is loaded on the train. The journey continues by rail, usually on long national or international routes. At the destination terminal another vehicle withdraws the shipment and transport it to the final destination by road [1–3].

In this way the combined is the main part of inland intermodality transport.

To highlight the role of the combined mode in freight transport on a European scale, tables 1 and 2 are given.

- The major players in the road-rail intermodal sector on international and national scale with the amount of tonnes transported (table 1) [4];
- The main Italian terminal with quantities handled (table 2) [5].

For each terminal the reported values are:

- PT_{conv}/W = pairs of trains in a week, considering conventional transport;
- PT_{int}/W = pairs of trains in a week, considering combined transport;
- ha= hectare;
- UTI= unit of intermodal traffic;
- FC= flow of tonnes with combined mode (road-rail);
- FR= flow of tonnes with road mode.

To homogenize the values presented in table 2, it is assumed that:

- Flow of tonnes with combined mode in Rivalta Scrivia terminal = 45.433 containers handled x 30 tons (average weight 1UTI);
- Flow of tonnes with combined mode in Parma terminal = 86.400 (vehicles) x 30 tons (average weight 1UTI) = 2.6×10^6 ton on truck;
- Flow of tonnes with combined mode in Verona terminal = 11.646 (intermodal trains) x 600 tons (average value transported per train);
- Flow of tonnes with combined mode in Padova terminal = 700 (vehicle/day) x 30 tons (average weight 1UTI) x 300 (day work/year) = 8.4 x 106 ton on truck.

Table 1: Traffic of international players of combined road-rail (2011) [4].

Company	International traffic (ton/2011)	National traffic (ton/2011)
Kombiverkehr	17.179.000	10.518.000 (DE)
Hupac	16.263.480	2.092.440(CH)
Cemat	8.531.680	3.041.800(IT)
IFB	5.791.240	16.150.840(BE)
Ökombi	5.418.840	5.538.160(AT)
ICA	4.872.600	1.851.120(AT)
Adria Kombi	4.066.880	1.312.160(SI)
RAlpin	3.741.360	427.960(CH)
Hupac	2.785.280(NL)	-
Naviland Cargo	2.030.360	4.309.280(FR)
Polzug	1.690.040	326.640(PL)
Alpe Adria	1.494.240	457.520(IT)
Novatrans	1.216.200	5.178.240(FR)
Combiberia	918.600(ES)	-
Hungarocombi	636.040(HU)	-
Bohemiakombi	402.560(CZ)	-

Table 2: Pairs of train/week (PT/W) of Italian's Terminals and reference site [5].

Terminal	PT_{conv}/W	PT_{int}/W	ha	UTI	FC(ton)	FR(ton)
CIM Novara	45	103	58	200.778	-	-
Rivalta Scrivia	10	24	125	138.700	-	1.3×10^6
Parma	5	24	252	86.700	2.6×10^6	-
Bologna	16	46	371	89.326	-	4.4×10^6
Trento	4	108	100	105.902	3.5×10^6	12.8×10^6
Verona	12	146	420	296.213	6.9×10^6	20×10^6
Padova	2	102	200	136.000	-	8.4×10^6
Campano	3	23	-	35.683	-	4.2×10^5veic

1.2 The analytical model of combined transport

The development of freight traffics on European and intercontinental scale has highlighted the limitations of the use of monomodal transfer, especially for repetitive movements [1, 6].

None of the traditional modes could deal adequately with the new demands placed in the transportation sector. The intermodality, with a generic definition, and the inland combined arise from the use of the most basic ways to make a transport on a predefined relation [7]. The crucial element to which they are closely related to the role and functions of intermodal transport is given by the share of the total distance in partial routes travelling to each other with a specific carrier in order to minimize the overall generalized cost of transportation that is mainly an energetic cost.

The intermodal nodes must allow the transfer of loading units between the different units of transport, belonging to different modes, minimizing the generalized cost or, more generally, maximizing the benefit of the users to carry out the transport with a specific chain of basic modes.

The transhipment function addresses the technical operations where a physical move loading unit is associated.

This paper would like to deal with the issue of the transfer for the rail-road case. From the establishment of origin the loading unit (swap body, container, semi-trailer) is forwarded by road to the rail system. Trains block on the railway system are loaded and unloaded in nodes (intermodal terminals) suitable to the execution of the operations between road and rail. From the terminal of departure, the block train is forwarded, without any intermediate stops, to the end rail terminal.

The loaded unit is forwarded to the warehouses of final destination by road.

In the case of road-rail-road combined mode the expressions referred to the costs of the road, rail and combined mode (eqn. 1.a, 1.b, 1.c) can be formulated as:

$$C_s = K_s d \tag{1.a}$$

$$C_f = K_{f1} d_f + K_{f2}(d - d_f) \tag{1.b}$$

$$C_c = K_s d_f + K_t + K_{f2}(d - d_f) \quad \text{with } d > d_f \tag{1.c}$$

in which:
C_s = cost of traveling by road carrier;
C_f = cost of traveling by rail carrier;
C_c = cost of traveling through combined chain;
K_s = generalized cost per unit of distance on the road network;
K_t = generalized cost of movement at the terminals of exchange;
K_{f1} = generalized cost per unit of distance on the secondary rail network;
K_{f2} = generalized cost per unit of distance on the main rail network for direct connections between the main terminals;
d_f = total distance of the two main railway terminals from the places of origin and destination.

The competitiveness of the combined is determined by the value of K_t, that is the generalized cost of movement at the terminals.

The combined mode is competitive if $K_t < K_{f1} d_f - K_s d_f$.

In this case, the diagram representative of combined transport is the one proposed in fig. 1.

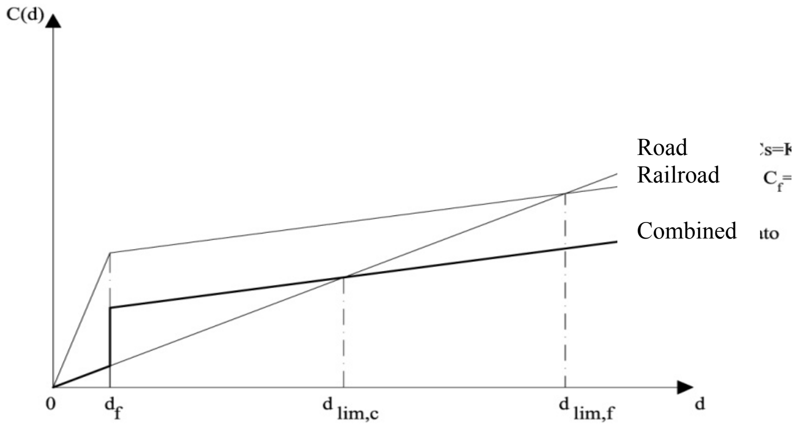


Figure 1: Cost distance diagram for the road-rail combined [1].

From the diagram it is clear that the cost of combined transport has a limit distance $d_{lim,c}$, beyond which it is more beneficial than road mode.

The lower the coefficient K_t is, more competitive is the terminal.

The reduction of generalized costs obtained with the introduction of intermodality between the different basic modes, therefore, increases the efficiency of transport services in multimodal cycles by providing the resources for the profit of the MTO (Multimodal Transport Operator) [8–10].

The aim of this paper is to study the formation of the generalized cost K_t.

As seen K_t is the synthetic element that, on the one hand, guarantees the efficiency of the terminal, and on the other, makes significant the use of intermodality.

2 Place and time of experimental survey

The Terminal Quadrante Europa, (Verona), is situated on the crossroads between Italy and Germany and the countries of Northern Europe, as well as the connecting line between Europe and the Eastern countries.

As part of the European network defined by the old UE Priority Projects (PP), the Terminal, is on the Milan–Venice railway line, which is part of the PP 6 (Lyon–Budapest), and on the railway line connecting Italy with Germany, PP1 (Berlin/Verona–Palermo).

In addition, the Terminal is located at the intersection between the A4 Turin–Venice motorway and the A22 Brennero motorway.

The terminal is part of the new TEN-T Core network, and is situated in the intersection between the corridor 3 "Mediterranean" from Algeciras to Budapest and the corridor 5 "Scandinavian–Mediterranean" from Helsinki to La Valletta [11, 12].

The terminal by means of corridor 3 is linked directly to the other two corridors involving Italy: the corridor 1 "Baltic–Adriatic" from Trieste and the corridor 6 "Reno–Alps" from Genova (fig. 2).

The Verona rail-road terminal is divided into three modules, each consisting of 5 tracks, for a total of 15 tracks with the respective platforms where the operators can drop loads for a short time slot. The first two modules are owned by RFI (Rete Ferroviaria Italiana) and managed by Terminali Italia; the third module called Terminal Gate, is owned by the Quadrante Europa Terminal Gate S.p.a. (50% RFI and 50% Consorzio ZAI), but is contracted out to Terminali Italia [13].

The operations that the truck driver can carry out within the terminal are:

- Delivery: the vehicle enters, loaded of one or two UTI (intermodal transport units), with the purpose of unload it/ them;
- Pick up: the vehicle enters with the purpose of collecting one or two full or empty UTI;
- Value-added services: without unloading, the vehicle arrives loaded with one or two UTI that need to undergo a specific process that increases the freight value as the repositioning on the truck, weighing.

The survey of the variables needed to study the terminal cycle has been carried out:

- through a manual survey of waiting time variables at pre check-in and waiting time at check-in;
- through the automatic surveys database from which the total times between the beginning and end of the terminal cycle for the vehicles served are obtained.

The period within which the temporal variables surveys were made is the week of January from 7 to 12, 2013; from 00:00 to 23:59 every day except on Saturday; Saturday was detected until 12:00.

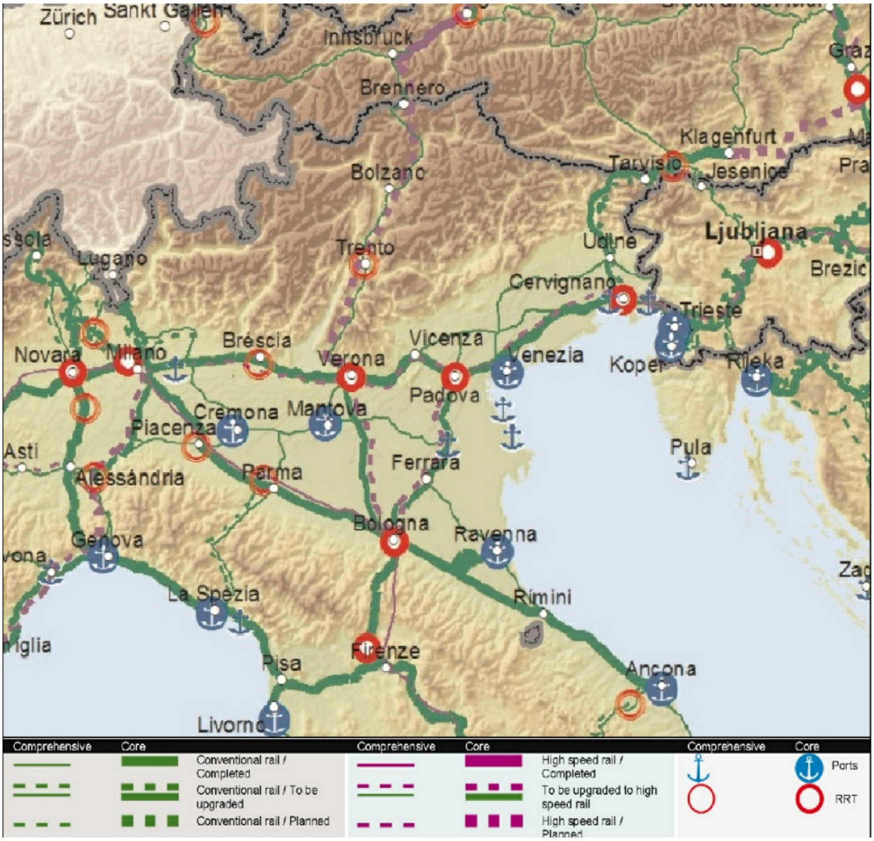


Figure 2: The Verona Rail Road Terminal (RRT) between the corridors CORE network [7].

3 Specification and calibration of the model

3.1 The specification

As seen the combined mode has as a crucial element in the knowledge of the aggregate variable K_t characteristic of each terminal that represents the generalized cost needed to pass the UTI from the road to the railway and from the railway to the road.

K_t is an average value that derive from:

- $K_{t,ex}$ value representing the UTI that arrive by truck and leave by train;
- $K_{t,in}$ representing UTI that arrive by train and leave by truck.

The main component of K_t is the time, in turn decomposable into three temporal variables depending on weather it is UTI at delivering, eqn. (2.a), or at withdrawal, eqn. (2.b), (fig. 3):

$$K_{t,ex} = t_{truck\_in,full} + t_{load,UTI} + t_{train\_ex,full} \tag{2.a}$$

$$K_{t,in} = t_{train\_in,full} + t_{unload,UTI} + t_{truck\_ex,full} \tag{2.b}$$

with:

$t_{truck\_in,full}$ time the vehicle takes from the pre check-in, at the entrance of the terminal, to the time of deposit UTI in the buffer of the terminal for the storage before the load;

$t_{load,UTI}$ time of movement of UTI from the time of deposit in the buffer to the pick up on the train;

$t_{train\_ex,full}$ waiting time from the load of UTI until the completion of the train and the forwarding to the train station;

$t_{train\_in,full}$ waiting time from the arrival of the train in the terminal to the UTI unloading;

$t_{unload,UTI}$ time of movement of UTI from the train to the buffer;

$t_{truck\_ex,full}$ time the vehicle takes from the loading of UTI, from the storage buffer, or from the arriving train, until the output from the terminal.

The total time $t_{CT,cons}$ for the truck that arrives loaded and exits unloaded is given by eqn. (3.a):

$$t_{CT,cons} = t_{truck\_in,full} + t_{truck\_ex,empty} \tag{3.a}$$

The total time $t_{CT,get}$ for the vehicle that arrives empty and exits unloaded is given by eqn. (3.b):

$$t_{CT,get} = t_{truck\_in,empty} + t_{truck\_ex,full} \tag{3.b}$$

To link the eqn. (2.a) to the eqn. (3.a) it's possible to make the assumption that the value of $t_{truck\_ex,empy}$, time is independent from the other movements in the terminal and is defined by

$$t_{truck\_ex,full} = \frac{l_{truck}}{Vc} \tag{4}$$

with:

l_{truck} = length of path that goes from the buffer to the output gate;

V_c = commercial speed inside the terminal = 30 km/h.

A similar hypothesis can be made to link eqn. (2.b) with eqn. (3.b).

The revealed element is t_{CT}, it is sampled both for the vehicles that arrive loaded and exit unloaded, $t_{CT,cons}$ and for the vehicles that arrive unloaded and exit loaded, $t_{CT,get}$.

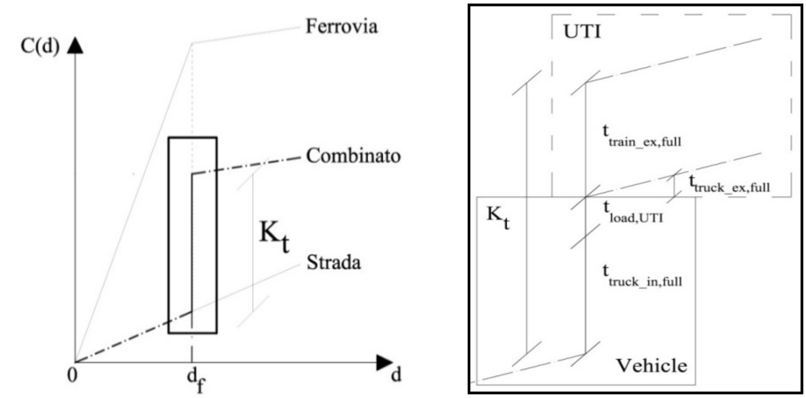


Figure 3: Graph vehicles movement in the terminal and representation of Kt.

3.2 The calibration

On the basis of the available data are calculated: $\mu_{ik}(t_{CT})$, the average time of the vehicle and $N_{ik,CT}$, the average number of accesses for a day, for different sets of operative time:

- for all the week, $[\mu_{week}(t_{CT}), N_{CT\_week}]$;
- for the generic day i, $[\mu_i(t_{CT}), N_{i,CT}]$;
- for the generic slot k of the generic day i, $[\mu_{ik}(t_{CT}), N_{ik,CT}]$.

3.2.1 Reference times and flows in the terminal

On the basis of the available values of the surveys the average time of the cycle t_{CT} and its variance can be calibrated in different build samples, as well as the number of accesses in the time unit with the relative variance, defined previously.

In the following it will be presented only tree cases that represent the significant operative conditions for the terminal (table 3).

Case A) Average values over the whole sample:

$[\mu_{week}(t_{CT})]$, $s^2[\mu_{week}(t_{CT})]$;

$[N_{CT,week}]$, $s^2[N_{CT,week}]$;

Case B) Average values over the whole sample excluding Saturday:

$[\mu_{week^*}(t_{CT})]$, $s^2[\mu_{week^*}(t_{CT})]$;

$[N_{CT,week^*}]$, $s^2[N_{CT,week^*}]$.

Case C) Average values over the whole sample considering the time slot 06:00–21:00 and excluding Saturday:

$[\mu_{week^*,06:00–21:00}(t_{CT})]$, $s^2[\mu_{week^*,06:00–21:00}(t_{CT})]$;

$[N_{CT,week^*,06:00–21:00}]$, $s^2[N_{CT,week^*,06:00–21:00}]$.

Table 3: Aggregated values of the terminal cycle time and of the number of accesses.

Case	Average time (sec)	Variance time (sec^2)
A	1479	349.205
B	1455	194.581
C	1477	150.608
Case	**Average flows (1/hour)**	**Variance flows (1/hour)^2**
A	21	291
B	22	295
C	27	275

3.2.2 Relation between times and flows inside the terminal

A specific analysis is developed to determine whether there is a relationship between the average cycle time in an hour and the flow of vehicles services in the same slot time.

In fig. 4 it's presented a scatter diagram of the flows and average service time in all the slot hours sampled.

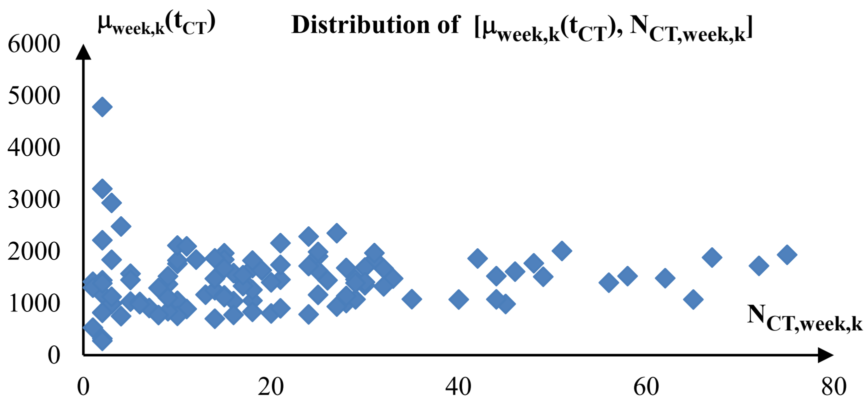


Figure 4: Scatter diagram average time and flow vehicle on all week.

The numerical analysis is carried through the study of the correlation coefficient, ρ_z, that takes the value of ± 1 if the two variables sampled are perfectly correlated.

The coefficient is zero if the two variables are mutually not related.

Being that:

$$\rho_z = \frac{\widehat{Cov}[x,y]}{\sqrt{\widehat{Var}[x]\widehat{Var}[y]}} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\left(\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2\right)\left(\frac{1}{n-1}\sum_{i=1}^{n}(y_i-\bar{y})^2\right)}} \quad (5)$$

the covariance, $\widehat{Cov}[x,y]$, between $\mu_{ik}(t_{CT})$ and $N_{ik,CT}$ is calculated using the value:

$$\widehat{Cov}[\mu_{ik}(t_{CT}); N_{ik,CT}] = \frac{1}{n}\sum_{i=1}^{n}(N_{ik,CT} - \overline{N_{CT}})(\mu_{ik}(t_{CT}) - \overline{\mu(t_{CT})}) \qquad (6)$$

The calculated coefficient for the three samples defined in the previous paragraph results (table 4):

Table 4: Index of linear correlation z.

Case	$Var[\mu_{ik}(t_{CT})]$	$Var[N_{ik,CT}]$	$Cov[\mu_{ik}(t_{CT});N_{ik,CT}]$	ρ_z
A	349.205	291	748	0.07
B	194.581	295	2.345	0.31
C	150.608	275	1.386	0.21

The intervals that distinguish the degree of correlation between variables are of three types for direct correlation (and similarly for the inverse):

- weak correlation $0 < \rho_z < 0.3$
- moderate correlation $0.3 < \rho_z < 0.7$
- strong correlation $0.7 < \rho_z < 1$

From table 4 results a weak correlation between variables for case A and B, and near to weak for case C.

Considering these results it is possible to conclude that the service time is not correlated with the flow. The presence of the value 0.31 and 0.21 indicate the opportunity of other analyses in other terminals.

3.2.3 The maximum level for time and flows

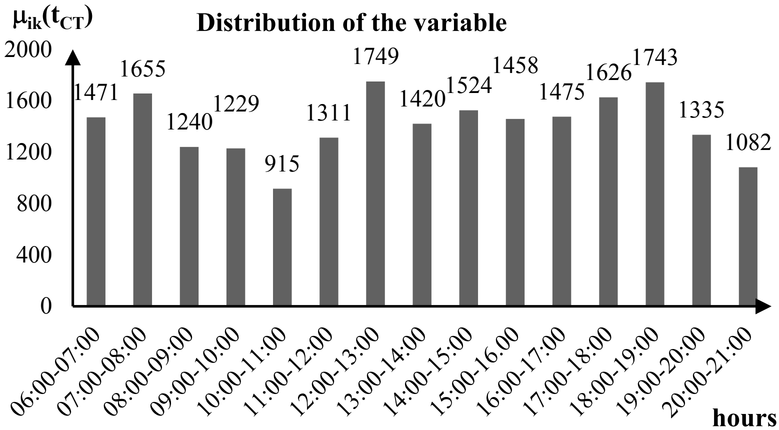
Figs 5a and 5b represent the flows trend and the cycle terminal average time, adding for all days, from Monday to Friday, the number of arrivals and making the time average, in the time slot 06:00–21:00.

Analyzing the diagram in fig. 5a and in fig. 5b it can be seen that there is a maximum in the number access of the slot 18:00–19:00, and two previous relative maximum in the slots 07:00–08:00 and 12:00–13:00:

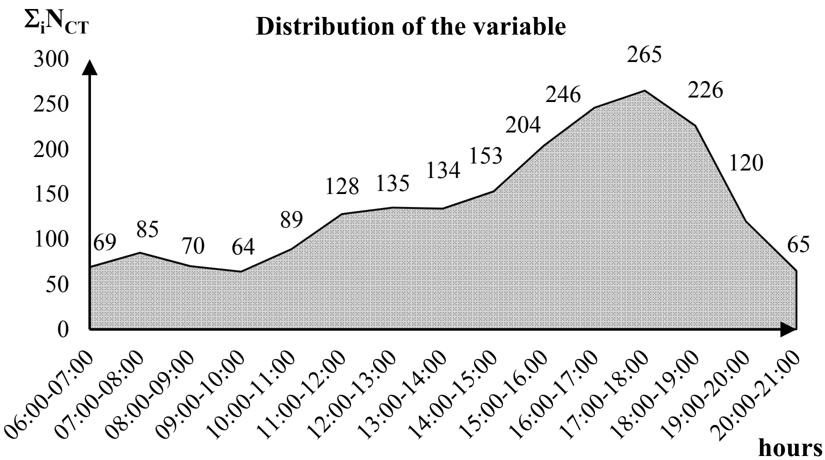
$N_{CT,\ week*07:00–08:00} = 85$ with $\mu_{week*,07:00–08:00}(t_{CT}) = 1680$ sec;
$N_{CT,\ week*12:00–13:00} = 135$ with $\mu_{week*,12:00–13:00}(t_{CT}) = 1749$ sec;
$N_{CT,\ week*18:00–19:00} = 226$ with $\mu_{week*,18:00–19:00}(t_{CT}) = 1743$ sec.

Finally have been calculated the statistics for these sets of slots that emphasise a weak correlation.

These results confirm the good performance of the terminal. In fact the average service time, and then the terminal cycle time in the road-rail combined transport, in Quadrante Europa, aren't correlated with the UTI land truck flow, indicating that the process are operated in an industrial ways without capacity problems.



(a)



(b)

Figure 5: (a) Distribution cycle terminal average time – Case C, (b) distribution number of arrivals – Case C.

Acknowledgement

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