RAILWAY ENGINEERING

PROF. STEFANO RICCI

RAILWAY PROJECT

ANALYZING THE RAILWAY LINE OF THE

CASTEL LAGOPESOLE – POTENZA CENTRALE

STUDENT:

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I. PROJECT WORK

For the section from Castel Lagopesole to Potenza Centrale (see Planimetry – Profile)

1. To determine the maximum allowed speed along all curves taking into account the following hypothesis
    - Maximum super-elevation of external rail – 160 [mm]
    - Maximum unbalanced acceleration – 0.8 [m/s^2]
2. To represent the maximum allowed speed in a v – s diagram

Solution:

The first step of the analysis was the calculation of the speeds along the line, taking in account only the planimetric development, specifically the radius of the curves on the line.

In the straight lines, it was assumed a speed of [V = 120 kmph], while on the curves it was assumed an unbalanced acceleration equal to [a = 0.8 m/s^2], giving the speed equal to

$$V = \sqrt{((a+g*\sin(\gamma))*R)}$$

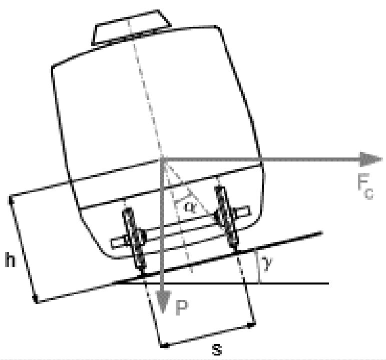
$$V = 4.89 * \sqrt{R}\ [km/hr]$$

The Equation 1 has been found evaluating the condition of over-tilting, assuming a super elevation of the external rail equal to the maximum value valid in Italy,

h = 160 [mm] [Figure 2]

Then it was calculated the unbalanced force subtracting the contribution of the weight to the centrifugal force [Equation 2]

$$\vec{F}_{unb} = \vec{F}_{cent} + P$$



Among these 2 stations there are 3 intermediate stations which are represented in the table.

Number	Station	Progressive Distance (m)
1	Castel Lagopesole	94468
2	Pietragalla	99715
3	Avigliano Lucania	104320
4	Potenza Superiore	114520
5	Potenza Centrale	118329

Between each station, there are the sequent values of time, minimum radius and average speed which according to the actual condition are reported in table

All Sections	Minimum Radius [m]	Time [min]	Average Speed [km/hr]	Average Speed [m/s]

Castel Lagopesole - Pietragalla	300	7	43.80	12.17
Pietragalla - Avigliano Lucania	300	5	55.30	15.36
Avigliano Lucania - Potenza Superiore	290	13	38.00	10.56
Potenza Superiore - Potenza Centrale	250	11	20.80	5.78

There are 31 curves among these stations and the maximum allowed speed are calculated for all of the curves, but for those curves which the maximum speed were higher than 120 [km/h], the 120 [km/h] were assumed, because with respect to the Italian Railway standard the maximum speed is for straight lines which is equal to 120 [km/h].

Curves	Radius [m]	Max Allowed Speed [Km/hr] (Theoretical)	Max Allowed Speed [Km/hr] (Practical)
1	400	97.70	97.70
2	400	97.70	97.70
3	400	97.70	97.70
4	300	84.61	84.61
5	300	84.61	84.61
6	600	119.66	119.66
7	800	138.17	120.00
8	500	109.23	109.23
9	300	84.61	84.61
10	800	138.17	120.00
11	500	109.23	109.23
12	650	124.54	120.00
13	300	84.61	84.61
14	600	119.66	119.66
15	400	97.70	97.70
16	300	84.61	84.61
17	300	84.61	84.61
18	300	84.61	84.61
19	400	97.70	97.70
20	600	119.66	119.66
21	3000	267.56	120.00
22	500	109.23	109.23
23	400	97.70	97.70
24	290	83.19	83.19
25	290	83.19	83.19
26	400	97.70	97.70
27	250	77.24	77.24
28	300	84.61	84.61
29	300	84.61	84.61
30	300	84.61	84.61
31	850	142.42	120.00

Curves	Radius [m]	Start [km]	End [km]	V [km/hr]
1	400	94.70	94.95	97.70
	0	94.95	95.15	120.00
2	400	95.15	95.30	97.70
	0	95.30	95.41	120.00

3	400	95.41	95.60	97.70
	0	95.60	96.28	120.00
4	300	96.28	96.61	84.61
	0	96.61	98.23	120.00
5	300	98.23	98.38	84.61
	0	98.38	98.55	120.00
6	600	98.55	98.71	119.66
	0	98.71	99.20	120.00
7	800	99.20	99.44	120.00
	0	99.44	99.70	120.00
8	500	99.70	99.96	109.23
	0	99.96	103.50	120.00
9	300	103.50	103.78	84.61
	0	103.78	106.14	120.00
10	800	106.14	106.36	120.00
	0	106.36	106.92	120.00
11	500	106.92	107.17	109.23
	0	107.17	107.32	120.00
12	650	107.32	108.02	120.00
	0	108.02	108.31	120.00
13	300	108.31	108.53	84.61
	0	108.53	108.85	120.00
14	600	108.85	108.97	119.66
	0	108.97	109.36	120.00
15	400	109.36	109.45	97.70
	0	109.45	109.54	120.00
16	300	109.54	109.75	84.61
	0	109.75	109.98	120.00
17	300	109.98	110.33	84.61
	0	110.33	110.48	120.00
18	300	110.48	110.69	84.61
19	400	110.69	110.82	97.70
	0	110.82	112.58	120.00
20	600	112.58	112.86	119.66
21	3000	112.86	112.99	120.00
22	500	112.99	113.11	109.23
	0	113.11	113.51	120.00
23	400	113.51	113.64	97.70
	0	113.64	113.77	120.00
24	290	113.77	114.24	83.19
25	290	114.24	114.83	83.19
	0	114.83	114.96	120.00
26	400	114.96	115.43	97.70
	0	115.43	115.75	120.00
27	250	115.75	116.13	77.24
	0	116.13	116.51	120.00
28	300	116.51	117.14	84.61
	0	117.14	117.24	120.00

29	300	117.24	117.65	84.61
	0	117.65	117.76	120.00
30	300	117.76	117.87	84.61
31	850	117.87	118.10	120.00

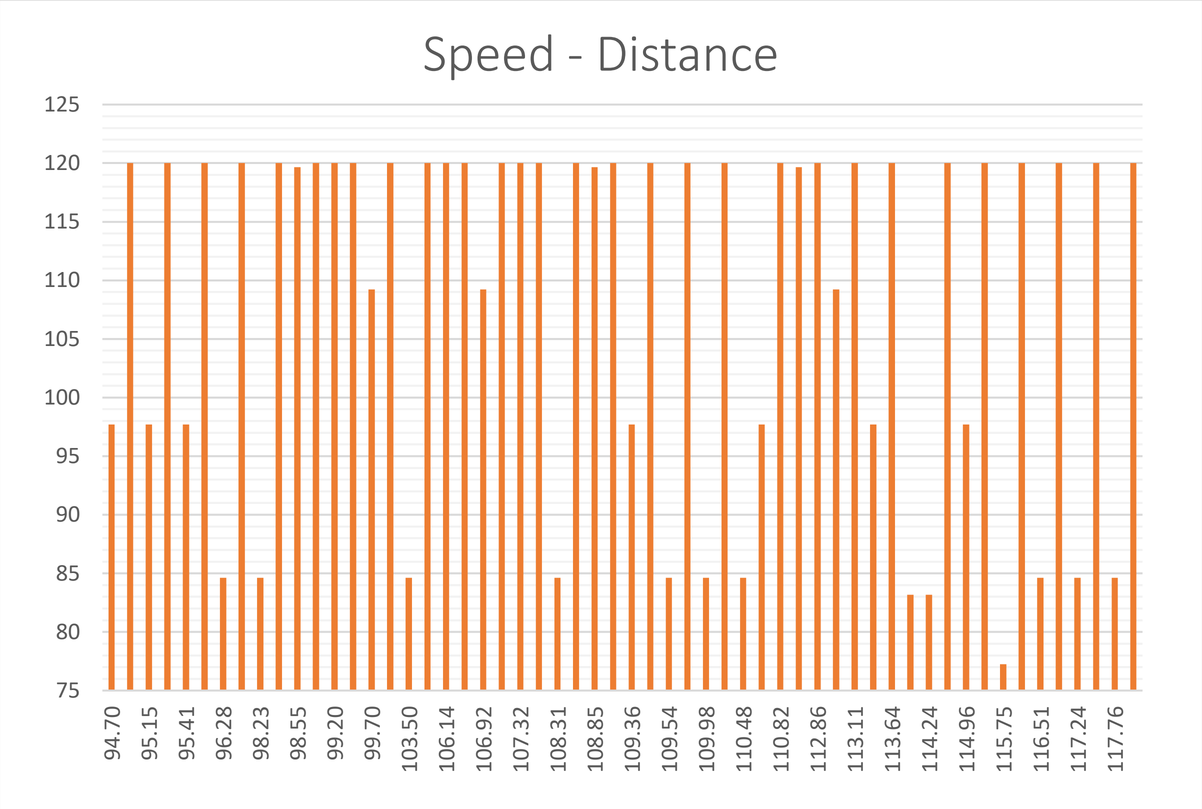


Figure 1: *Speed – Distance Diagram*

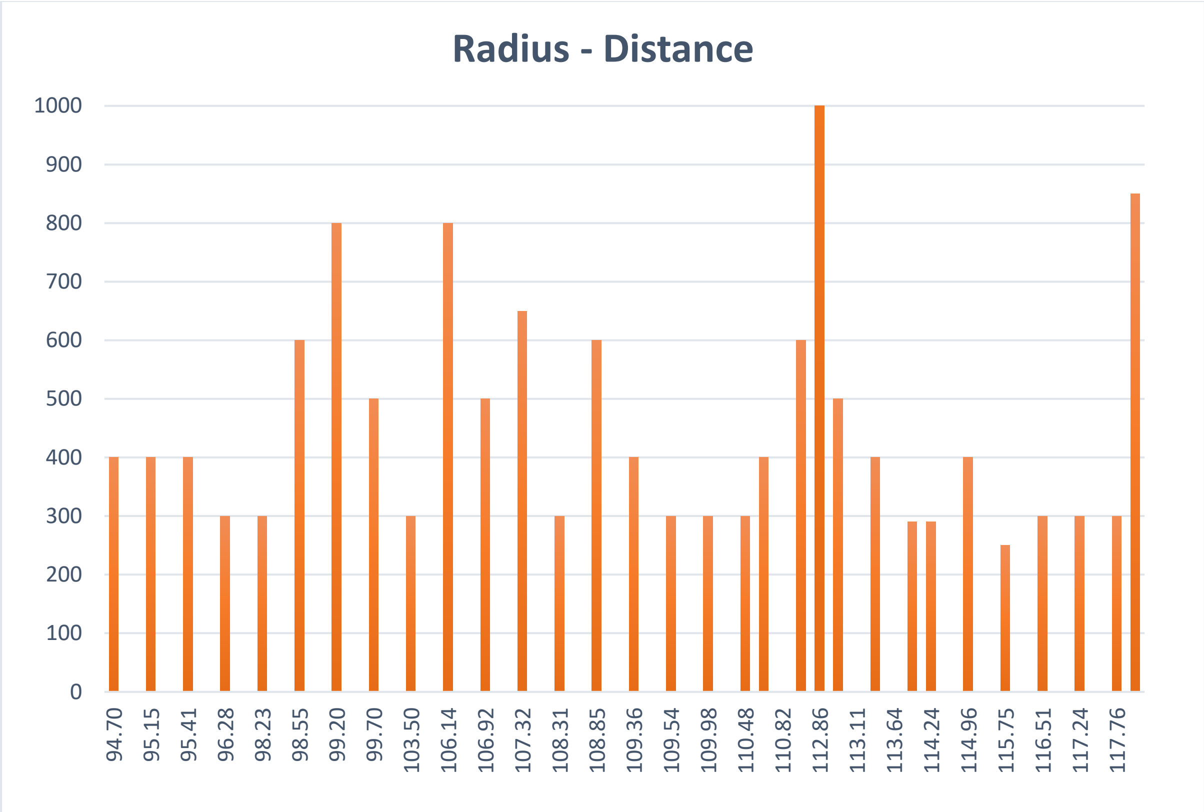


Figure 2: *<u>Radius – Distance Diagram</u>*

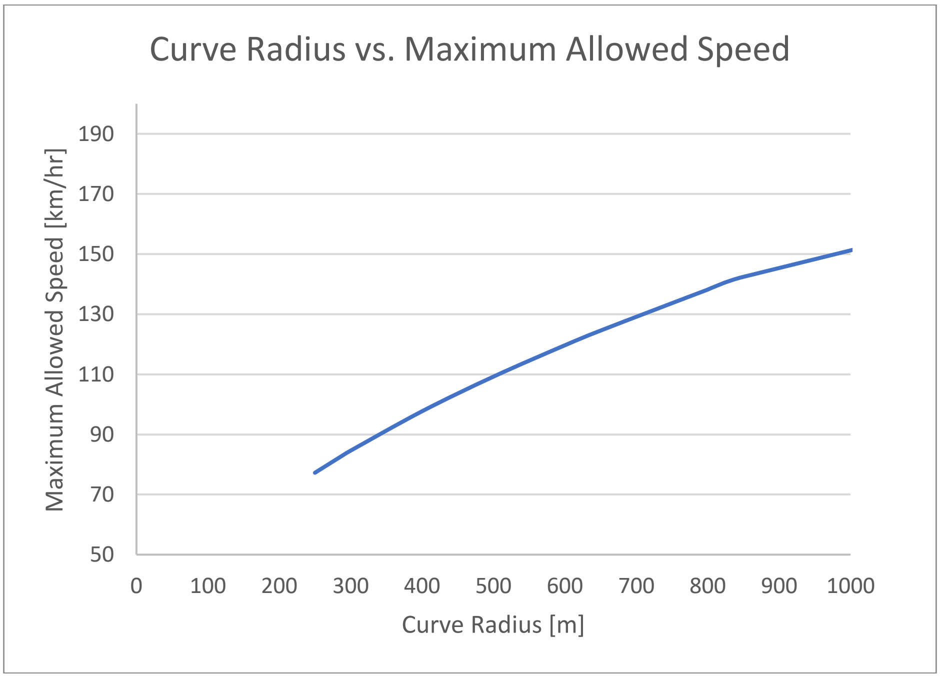


Figure 3: *<u>Curve Radius – Maximum allowed speed diagram</u>*

II. PROJECT WORK

For the section from Castel Lagopesole to Potenza Centrale (see planimetry-profile)

1. To determine the length and schematically draw the horizontal transition curves (cubic parabola) between curves and straight sections taking into account the following hypothesis

   - Acceleration variation = speed x unbalanced acceleration / length
   - Maximum acceleration variation: 0.14 [m/s^2]

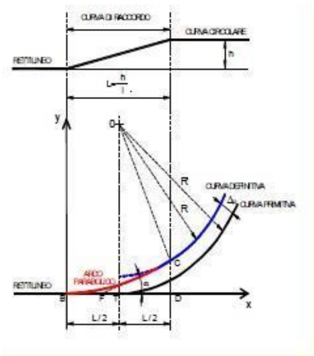
2. To determine the length and schematically draw the vertical circular transition curves between the couples of slopes taking into account the following hypothesis

   - Radius = (speed)^2 /vertical acceleration
   - Maximum vertical acceleration: 0.4 [m/s^2]

Solution:

Horizontal transition curves

Approaching the curve, the train will pass from a super elevation (say, e = 0) to the one it has been chosen, equal to the maximum allowable value [h = 160 mm].



It's not possible an immediate passage between these two values, but it needs a transition curve. Its length will depend on three parameters.

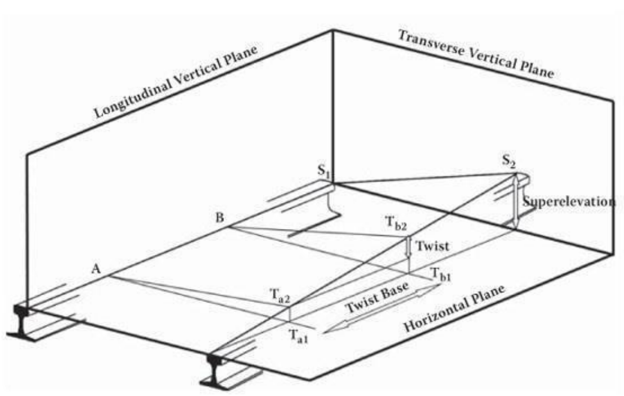
$$v = \text{speed}, [m/s]$$

$$\Delta a = 0.14\ [m/s^2],\ acceleratiion\ variation$$

$$a = 0.8\ [\mathrm{m/s^2}],\ unbalanced\ acceleration$$

Calculation of the length:

$$L_h = v \cdot a_{unb} / \Delta a\ [m]$$



Radius [m]	Speed [Km/hr]	Speed [m/s]	Unbalanced Acceleration Variation [m/s^2]	Acceleration Variation [m/s^2]	Transition Curve Length [m]
250	77.24	21.46	0.80	0.14	123
290	83.19	23.11	0.80	0.14	132
300	84.61	23.50	0.80	0.14	134
400	97.70	27.14	0.80	0.14	155
500	109.23	30.34	0.80	0.14	173
600	119.66	33.24	0.80	0.14	190
650	124.54	34.60	0.80	0.14	198
800	138.17	38.38	0.80	0.14	219
850	142.42	39.56	0.80	0.14	226
3000	267.56	74.32	0.80	0.14	425

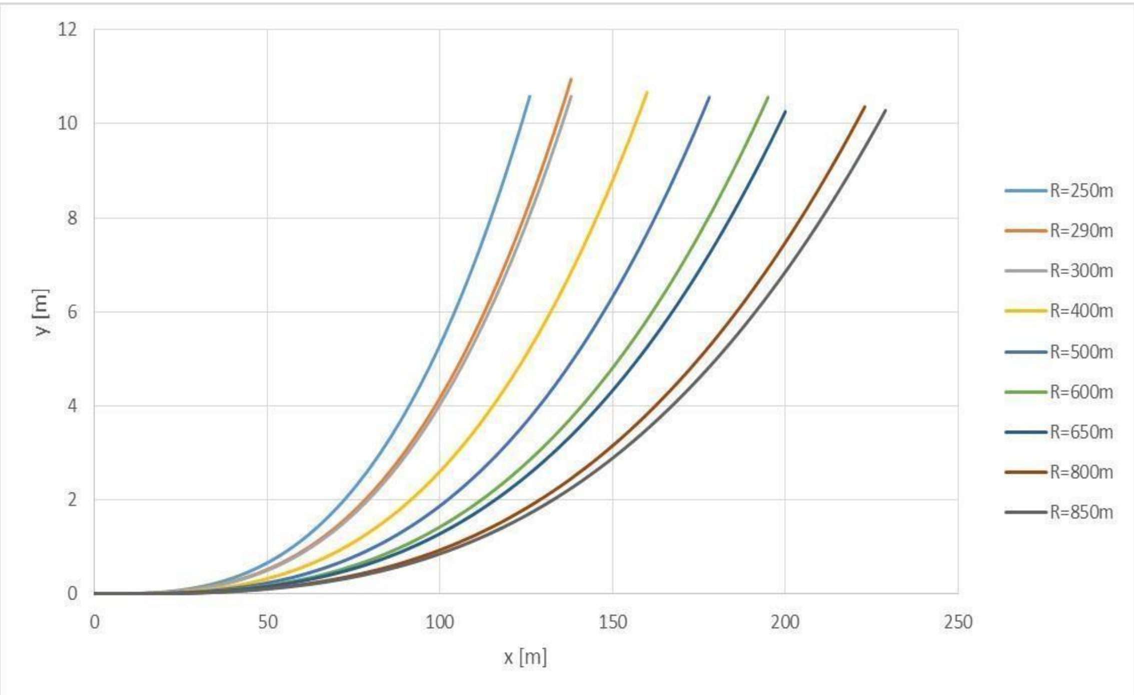
The most used transition curves are:

- Cubic parabola (traditional)
- Sinusoidal (over 200 km/h)
- Partial spiral (clothoid, used for Roads[Highways])

The chosen transition curve is the **"parabolic curve",** with general equation given

$$y_x = x^3 / 6RL_h$$

The length of the curve put in the equation should be projected on the x-axis, but the ratio yy/xx is so low that it's possible to equalize the projection to the length of the curve. With these considerations, they were drawn the sequent parabolic curves



Curves	Radius [m]	Max Allowed Speed [Km/hr] (Practical)	Speed [m/s]	Transition Curve Length [m]

1	400	97.70	27.14	155
2	400	97.70	27.14	155
3	400	97.70	27.14	155
4	300	84.61	23.50	134
5	300	84.61	23.50	134
6	600	119.66	33.24	190
7	800	120.00	33.33	190
8	500	109.23	30.34	173
9	300	84.61	23.50	134
10	800	120.00	33.33	190
11	500	109.23	30.34	173
12	650	120.00	33.33	190
13	300	84.61	23.50	134
14	600	119.66	33.24	190
15	400	97.70	27.14	155
16	300	84.61	23.50	134
17	300	84.61	23.50	134
18	300	84.61	23.50	134
19	400	97.70	27.14	155
20	600	119.66	33.24	190
21	3000	120.00	33.33	190
22	500	109.23	30.34	173
23	400	97.70	27.14	155
24	290	83.19	23.11	132
25	290	83.19	23.11	132
26	400	97.70	27.14	155
27	250	77.24	21.46	123
28	300	84.61	23.50	134
29	300	84.61	23.50	134
30	300	84.61	23.50	134
31	850	120.00	33.33	190

The curvature of this kind of transition will be given by Equation: $1/\rho = 1/RL$

Where

R = Final curve radius
ρ = Curvature
L = Projection of curve on X axis
S = Mileage point
Minimum extension depending on maximum rotation speed (0.02 – 0.03 rad/s)

For the second part of the project work 2, the vertical transition curves should be calculated. The track presents many slopes and climbs along the line, the maximum allowable slope on primary lines equal to 35%. In this project for the climb a positive value and for the slope a negative value is chosen. Then the distances in which the different inclinations are occurred was reported in below table:

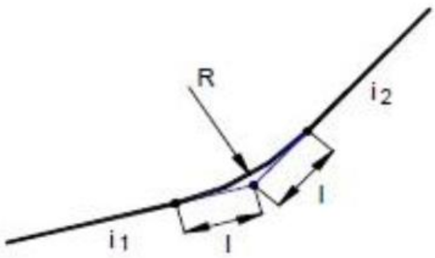
LENGTH OF VERTICAL TRANSITION CURVES

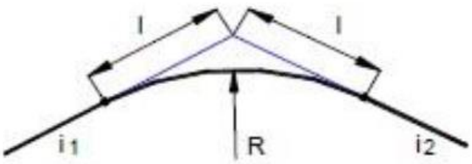
Curves	Max Allowed Speed [Km/hr] (Theoretical)	Speed [m/s]	a_v [m/s2]	Radius [m]	Radius >2000 [m]	i_1 [%]	i_2 [%]	Vertical Transition Curve, L [m]
1	120.00	33.33	0.4	2777.78	2777.78	0	25	34.72
2	84.60	23.50	0.4	1380.63	2000.00	25	3	28.00
3	120.00	33.33	0.4	2777.78	2777.78	3	1	5.56
4	120.00	33.33	0.4	2777.78	2777.78	1	0	1.39
5	120.00	33.33	0.4	2777.78	2777.78	0	-4	5.56
6	120.00	33.33	0.4	2777.78	2777.78	-4	-7	15.28
7	84.60	23.50	0.4	1380.63	2000.00	-7	0	7.00
8	120.00	33.33	0.4	2777.78	2777.78	0	10	13.89
9	120.00	33.33	0.4	2777.78	2777.78	10	0	13.89
10	120.00	33.33	0.4	2777.78	2777.78	0	-18	25.00
11	120.00	33.33	0.4	2777.78	2777.78	-18	-5	18.06
12	120.00	33.33	0.4	2777.78	2777.78	-5	-15	27.78
13	109.00	30.28	0.4	2291.86	2291.86	-15	-2	14.90
14	120.00	33.33	0.4	2777.78	2777.78	-2	-10	16.67
15	120.00	33.33	0.4	2777.78	2777.78	-10	0	13.89
16	84.60	23.50	0.4	1380.63	2000.00	0	12	12.00
17	120.00	33.33	0.4	2777.78	2777.78	12	18	8.33
18	120.00	33.33	0.4	2777.78	2777.78	18	7	34.72
19	120.00	33.33	0.4	2777.78	2777.78	7	0	9.72
20	120.00	33.33	0.4	2777.78	2777.78	0	-3	4.17
21	120.00	33.33	0.4	2777.78	2777.78	-3	-4.7	10.69
22	120.00	33.33	0.4	2777.78	2777.78	-4.7	0	6.53
23	120.00	33.33	0.4	2777.78	2777.78	0	-20	27.78
24	97.70	27.14	0.4	1841.30	2000.00	-20	-24.7	44.70
25	77.20	21.44	0.4	1149.66	2000.00	-24.7	-20	4.70
26	77.20	21.44	0.4	1149.66	2000.00	-20	-25	45.00
27	120.00	33.33	0.4	2777.78	2777.78	-25	-13	16.67
28	120.00	33.33	0.4	2777.78	2777.78	-13	0	18.06

III. PROJECT WORK

TIMETABLE DESIGN

For the section from Castel Lagopesole to Potenza Centrale



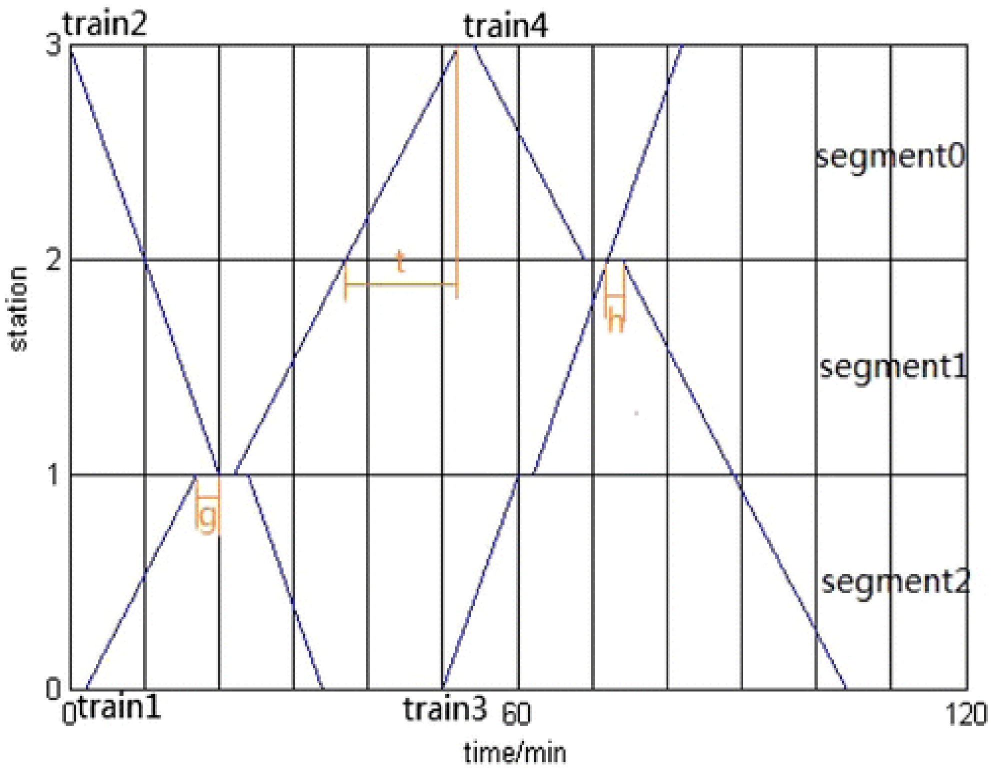


$$l = \frac{R}{2000}(i_2 - i_1) \qquad l = \frac{R}{2000}(i_2 + i_1)$$

1. To determine departure and arrival times from/to the stations of the section, for both directions, by assuming a minimum 10% additional (buffer) running time.

2. To design a 3-hour timetable taking into account.
   - The crossing of trains in stations only.
   - A reference frequency of 2 [trains/hour/direction].
   - A minimum stop time in stations of 60 [s].

3. To determine the commercial speed of the resulting service on both directions.



In the first phase, the max possible timetable is realized, without evaluating the acceleration and breaking phases or the contribution given by the slopes, but they're only evaluated the speeds on straight lines and on curves. To find the average speed between each couple of stations, it was used the sequent equation:

$$V_{avg} = \sum l_i \cdot V_i \Big/ \sum l_k$$

Section	Station 1	Station 2	Distance [m]	Average Speed [km/hr]	Average Speed [m/s]	Run Time [sec]
Castel Lagopesole - Pietragalla	94468	99715	5247	114	31.67	165
Pietragalla – Avigliano	99715	104320	4605	117	32.50	141
Avigliano – Potenza Superiore	104320	114520	10198	113	31.39	324
Potenza Superiore – Potenza Centrale	114520	118320	3820	104	28.89	134

Several assumptions are done in order to allocate the runs

- A frequency of 2 trains/hour/direction
- A minimum of 60 sec in the stations to allow the load and unload of passengers
- The run time must be increased of 10% in order to have a buffer time in case of delay

In the next pages, they are shown 2 different solutions to the problem. The buffer time is added to the stop time in each station.

Section	Run Time [sec]	Increased Run Time [sec]	Difference [sec]
Castel Lagopesole - Pietragalla	165	182	17
Pietragalla – Avigliano	141	155	14
Avigliano – Potenza Superiore	324	356	32
Potenza Superiore – Potenza Centrale	134	147	13

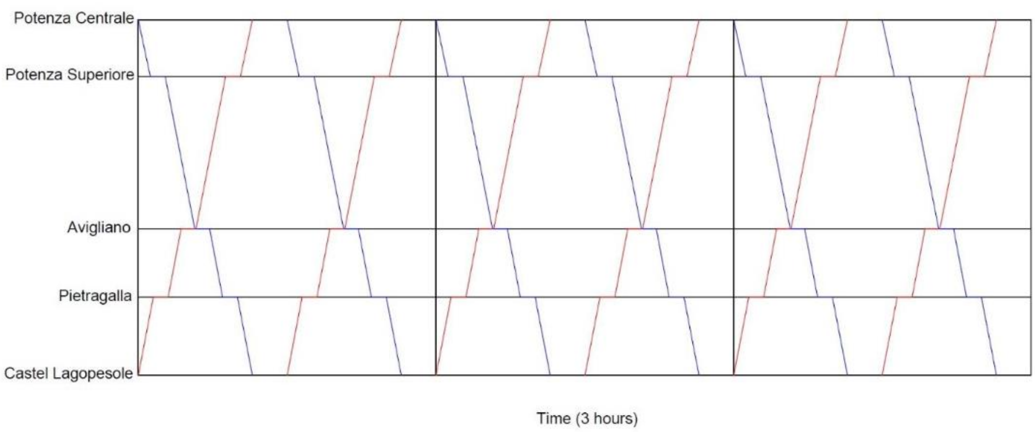
So, now the average speed is calculated by considering to the increased running time

Section	Distance [m]	Increased Run Time [sec]	Average Speed [km/hr]	Average Speed [m/s]
Castel Lagopesole - Pietragalla	5247	182	104	28.89
Pietragalla – Avigliano	4605	155	106	29.44
Avigliano – Potenza Superiore	10198	356	103	28.61
Potenza Superiore – Potenza Centrale	3820	147	94	26.11

TIME TABLES

As it was said at the beginning of Chapter 3, the max timetables are going to be realized, evaluating only the information's given by the infrastructures of the line. At each intermediate station a stop time of 2 minutes is taken.

The sequent timetables are so realized:



First Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	10:00:00
Pietragalla	10:03:00	10:06:00
Avigliano	10:08:00	10:11:00
Potenza Superiore	10:17:00	10:20:00
Potenza Centrale	10:23:00	-

Second Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	10:00:00
Pietragalla	10:03:00	10:06:00
Avigliano	10:08:00	10:11:00
Potenza Superiore	10:17:00	10:20:00
Potenza Centrale	10:23:00	-

Third Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	10:30:00
Pietragalla	10:33:00	10:36:00
Avigliano	10:38:00	10:41:00
Potenza Superiore	10:47:00	10:50:00
Potenza Centrale	10:53:00	-

Fourth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	10:30:00
Pietragalla	10:33:00	10:35:00
Avigliano	10:38:00	10:41:00
Potenza Superiore	10:43:00	10:45:00
Potenza Centrale	10:48:00	-

Fifth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	11:00:00
Pietragalla	11:03:00	11:06:00
Avigliano	11:08:00	11:11:00
Potenza Superiore	11:17:00	11:20:00
Potenza Centrale	11:23:00	-

Sixth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	11:00:00
Pietragalla	11:03:00	11:05:00
Avigliano	11:08:00	11:11:00
Potenza Superiore	11:13:00	11:15:00
Potenza Centrale	11:18:00	-

Seventh Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	11:30:00
Pietragalla	11:33:00	11:36:00
Avigliano	11:38:00	11:41:00
Potenza Superiore	11:47:00	11:50:00
Potenza Centrale	11:53:00	-

Eighth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	11:30:00
Pietragalla	11:33:00	11:35:00
Avigliano	11:38:00	11:41:00
Potenza Superiore	11:43:00	11:45:00
Potenza Centrale	11:48:00	-

Ninth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	12:00:00
Pietragalla	12:03:00	12:06:00
Avigliano	12:08:00	12:11:00
Potenza Superiore	12:17:00	12:20:00
Potenza Centrale	12:23:00	-

Tenth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	12:00:00
Pietragalla	12:03:00	12:05:00
Avigliano	12:08:00	12:11:00
Potenza Superiore	12:13:00	12:15:00
Potenza Centrale	12:18:00	-

Eleventh Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	12:30:00
Pietragalla	12:33:00	12:36:00
Avigliano	12:38:00	12:41:00
Potenza Superiore	12:47:00	12:50:00
Potenza Centrale	12:53:00	-

Twelfth Train Time Table		
Stations	Arrive	Departure
Castel Lagopesole	-	12:30:00
Pietragalla	12:33:00	12:35:00
Avigliano	12:38:00	12:41:00
Potenza Superiore	12:43:00	12:45:00
Potenza Centrale	12:48:00	-

Finally, the commercial speed should be calculated for all the line from Castel Lagopesole till Potenza Centrale with considering the stopping time in each station:

	Section 1	Section 2	Section 3	Section 4	Total
Distance [m]	5247	4605	10200	3800	23852
Running Time [s]	182	155	356	147	840
Stop Time [s]	180	180	180	180	720
Time [s]	362	336	537	326	1561
Commercial Speed [m/s]	14.44	14.72	14.31	13.06	14.13
Commercial Speed [km/hr]	52.00	53.00	51.50	47.00	50.88

The Commercial Speed for this section of the line is equal to the 51 (km/h), and it is same for both directions, because the time duration and the total distance is as same as each other.

IV. PROJECT WORK

Calculation of running spaces and times

For the section from Castel Lagopesole to Potenza Centrale (see Planimetry-Profile):

With reference to (see following slide)

The diesel train-set DMU Class 150

- Total mass (tare + conventional load): 76.4 t

- Inertial Coefficient: 1.10

The electric train-set TAF

- Total mass (tare + conventional load): 273 t
- Inertial coefficient: 1.10

Motion resistances: $r = 1.5 + \frac{0.005 * S * V^2 * K}{P}$

Where

S = 10 [m^2]

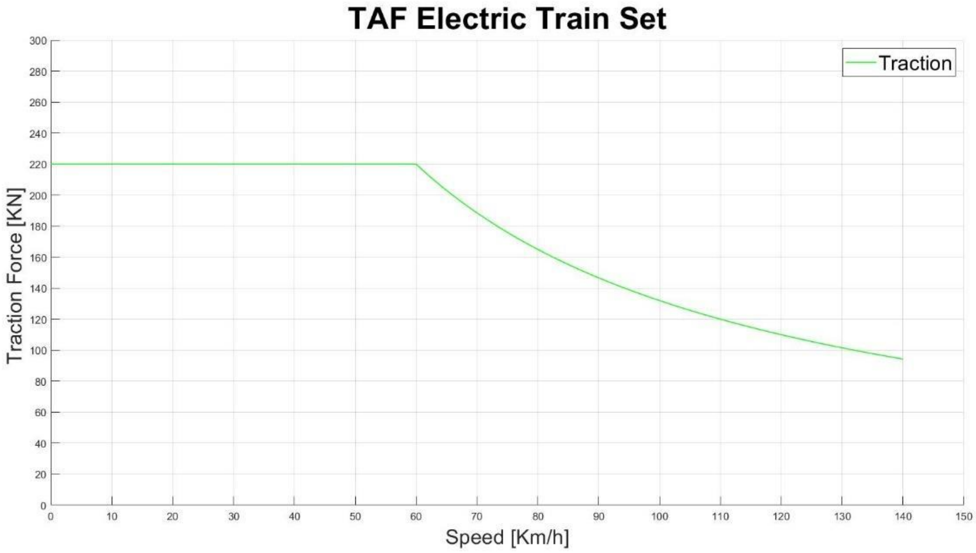
K = 0.71 (Breuer Formula)

Maximum speed to be derived by previous PWs and additional information taken from FCL Traffic Sheets (see following slides)

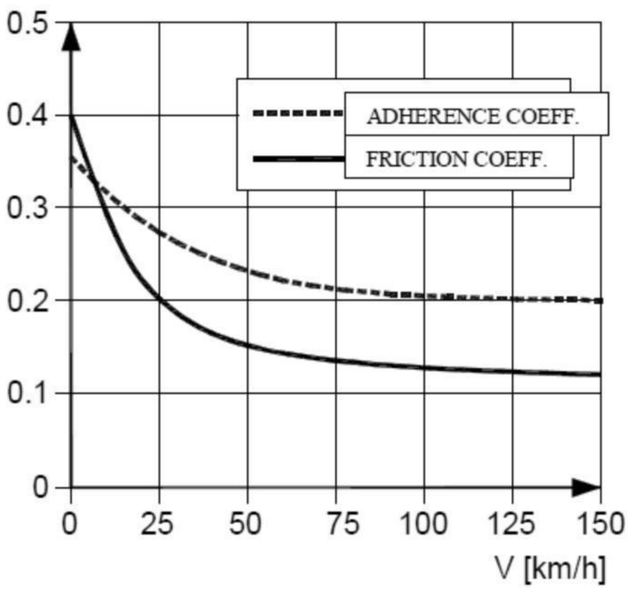
1. To calculate the running times on the first acceleration section starting from zero speed in the first station and reaching the maximum allowed speed (by Python tool)
2. To extend the calculation to the following sections, by taking into account speed limits and motion resistances variations, if any, and braking to stop in arrival stations (braking mass =110 % and friction coefficient to be derived by braking performances shown in the following slides),

The Calculation scheme is shown in the following slides as well.

In the previous Project work the timetables are calculated and represented without considering the type of the running trains, that will affect the performance of the line. On this line there are two types of trains should be considered.
The T-V curves of these two trains are reported in the below graph, which these 2 curves are so similar to each other, both have a constant traction till a certain value of the speed and then a hyperbolic decreasing according to the speed.
At first the traction speed diagram is calculated and represented in the below graph.



The braking performance and the friction coefficient and adherence coefficient is represented in the below graph.



Along the running from Castel Lagopesole to Potenza Centrale the train will encounter several resistances:

1. Slope Resistance
2. Inertial Resistance
3. Air Resistance

During the braking phases, when wants to reduce the speed to stop or just decrease somehow the speed, the train will have a braking mass higher of the 10% respect to the mass and a friction coefficient that increase hyperbolically during the deceleration.

The run has different phases:

1. Acceleration Phase: T - R = m * (1+B)
2. Cursing Phase: V = constant
3. Braking Phase: T + R = m * (1+B)

The running time from the Castel Lagopesole to Potenza Centrale is represented in the below table, on the other hand the running time from Potenza Centrale to Castel Lagopesole is represented in the next graph, and the total running time in both directions is represented.

Column	DMU 150 - speed [km/hr]	TAF - speed [km/hr]	Time - DMU [sec]	Time - TAF [sec]	DMU	TAF
1	0	0			**Time**	**Time**
2	80	80	59.88	37.55	**Section 01**	**Section 01**
3	80	80	393.71	406.06		
4	0	0	31.25	31.25	485	475
5	105	105	57.98	58.49		
6	105	105	83.92	81.28		
7	85	85	12.15	12.15	**Section 02**	**Section 02**
8	85	85	33.40	33.40		
9	0	0	31.25	31.25	219	217
10	100	100	86.70	54.01		
11	100	100	78.48	97.72		
12	80	80	10.41	10.41	**Section 03**	**Section 03**
13	80	80	51.68	51.68		
14	0	0	31.25	31.25	259	245
15	75	75	54.20	34.03	**Section 04**	**Section 04**
16	75	75	135.80	164.20		
17	0	0	31.25	31.25	221	229

Running Time between 5 Stations from Castel Lagopesole to Potenza Centrale [sec]

Trainset	Model	Castel Lagopesole Avigliano	Avigliano PM Tiera	PM Tiera Potenza Superiore	Potenza Superiore Potenza Centrale
DMU Class 150	DIESEL	485	219	259	221
TAF	ELECTRIC	475	217	245	229

Running Time between 5 Stations from Potenza Centrale to Castel Lagopesole [sec]

Trainset	Model	Potenza Centrale Potenza Superiore	Potenza Superiore PM Tiera	PM Tiera Avigliano	Avigliano Castel Lagopesole
DMU Class 150	DIESEL	221	282	218	419
TAF	ELECTRIC	212	272	209	406

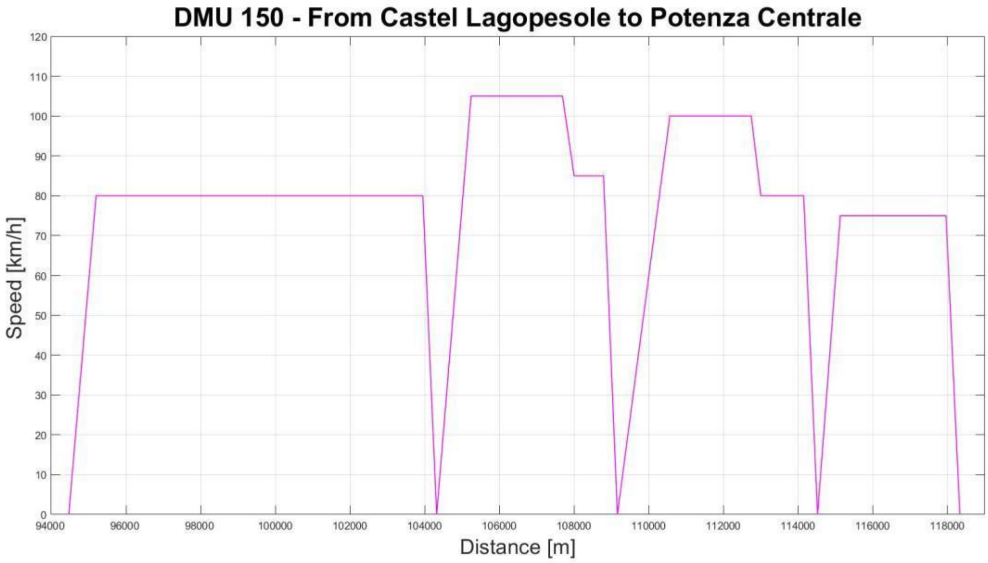
Total Running Time Between 5 Stations in both directions [sec]

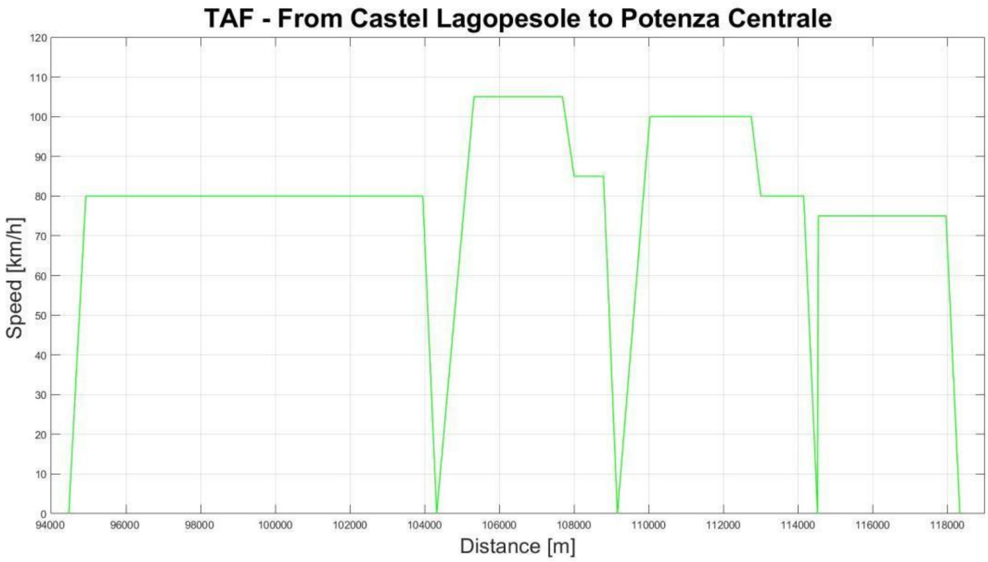
Trainset	Model	Castel Lagopesole to Potenza Centrale	Potenza Centrale to Castel Lagopesole
DMU Class 150	DIESEL	1183	1140
TAF	ELECTRIC	1166	1099

Total Running Time Between 5 Stations in both directions [min]

Trainset	Model	Castel Lagopesole to Potenza Centrale	Potenza Centrale to Castel Lagopesole
DMU Class 150	DIESEL	20	19
TAF	ELECTRIC	19	18

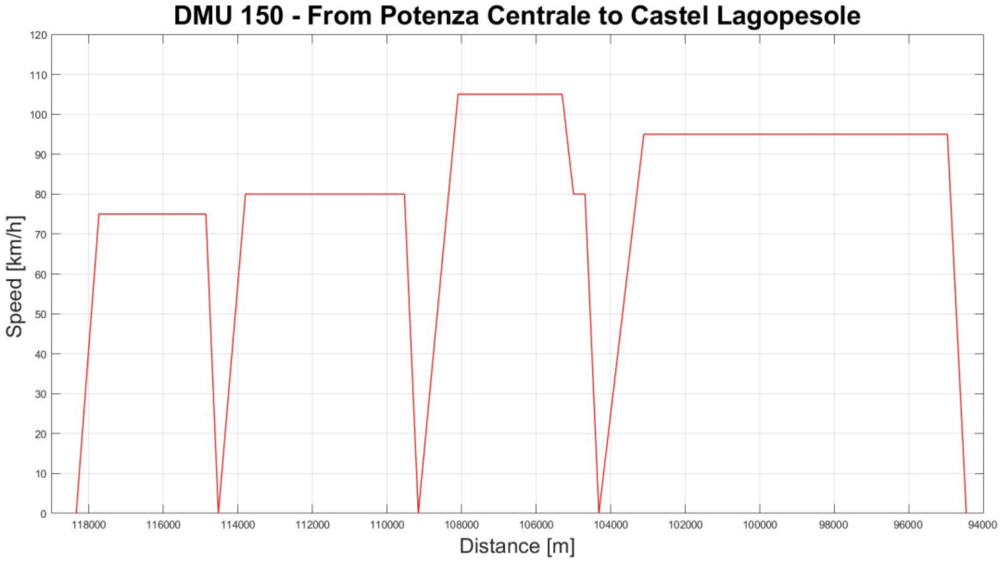
At first the speed-distance are calculated with variable acceleration and deceleration, but the result is not acceptable, because in the braking phase the deceleration is measured sometimes is equal to 3 [m/s^2] and it is not acceptable, because it is out of the comfort standard, so I decided to use a constant deceleration equal to 0.8, and the speed-distance diagram of both train-set is represented in below diagrams.

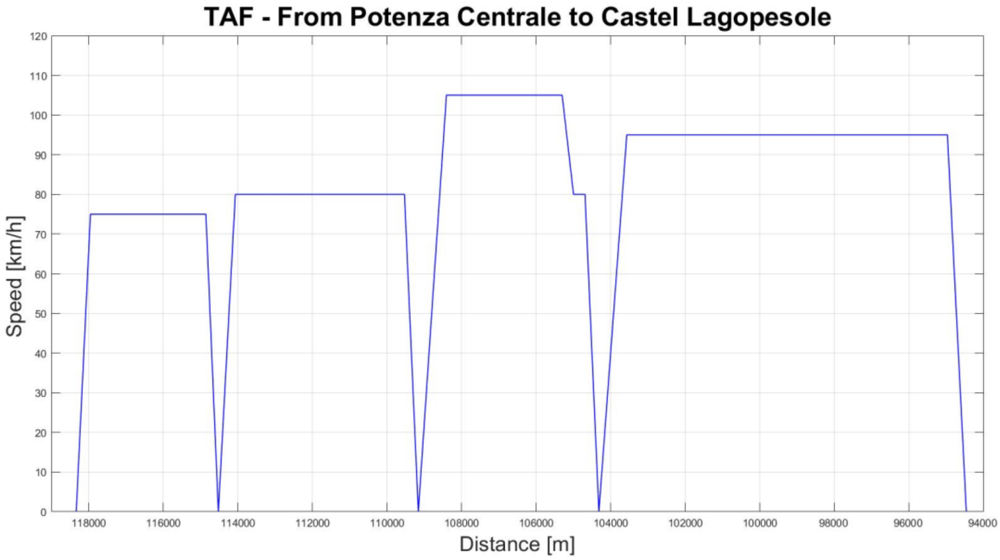




By looking to the both diagrams, it is obvious the Electric train which name is TAF is reached to maximum allowed speed quicker than the Diesel train which name is DMU 150, but because of constant deceleration the both deceleration part is as same as each other.

These diagrams are for the track between Castel Lagopesole to Potenza Centrale, but because of the maximum allowed speed in the opposite direction is not equal for this reason the speed distance diagrams are represented for the opposite direction in the below diagrams.





V. PROJECT WORK

Signal Positioning

For the section from Castel Lagopesole to Potenza Centrale

1. To position Main Signals (MS) and Advance Signals (AS) to protect stations and level crossing (LC) all considered automatically controlled, if any, by adopting the following reference distances:
   - AS – MS: 1000 [m]
   - MS – MS: 1350 [m]
   - MS – LC: 50 [m]
   - Single signals protecting various LC within 1500 [m]
   - Distance between all signals > 400 [m]

2. To plan the doubling of the track and correspondingly position track circuits (optionally signals) and balises for operating with ERTMS by assuming:
   - Track circuits length: 2000 m

Firstly the coordinates of all LC (Level Crossing) and Stations are obtained from the planimetry plan, then the coordinates of the MS (Main Signals) and AS (Advanced Signals) are calculated with respect to these coordinates, where the distance between 2 Level crossings or distance between level crossing and station is less than 1000 m for both of them just one AS (advanced Signal) and MS (Main Signal) are calculated.

I assumed the length of all stations are equal to 500 m and I put a MS (Main Signal) after 250 m of each Station, which is represented the occupancy of the station.

Single Track

In this case, the advance signal and main signals are used exactly with referred to the values are obtained from the project work information.

There is different LC between stations, So the most critical and important LC are between Avigliano Station and Potenza Superiore Station, which the all 6 Level Crossings are divided to 2 different groups, the first group has 2 LC and the second group has 4 LC.

Castel Lagopesole - Potenza Centrale				
Column	**Coordinates**	**Type of Signal**	**Description**	**Distance Between 2 Consecutive Signals**
1	**94468**	**Station**	**Castle Lagopesole**	**0**
2	94468	MS	Main Signal	0
3	97499	AS	Advance Signal	3031
4	98499	MS	Main Signal	1000
5	98549	LC	Level Crossing	50
6	98665	AS	Advance Signal	116

7	99665	MS	Main Signal	1000
8	**99715**	**Station**	**Pietragalla**	**50**
9	99715	MS	Main Signal	0
10	102975	AS	Advance Signal	3260
11	103975	MS	Main Signal	1000
12	104025	LC	Level Crossing	50
13	**104320**	**Station**	**Avigliano**	**295**
14	104320	MS	Main Signal	0
15	104736	LC	Level Crossing	416
16	105301	LC	Level Crossing	565
17	105560	AS	Advance Signal	259
18	106560	MS	Main Signal	1000
19	106610	LC	Level Crossing	50
20	106998	LC	Level Crossing	388
21	107863	LC	Level Crossing	865
22	108519	LC	Level Crossing	656
23	113470	AS	Advance Signal	4951
24	114470	MS	Main Signal	1000
25	**114520**	**Station**	**Potenza Superiore**	**50**
26	114520	MS	Main Signal	0
27	117279	AS	Advance Signal	2759
28	118279	MS	Main Signal	1000
29	**118329**	**Station**	**Potenza Centrale**	**50**

Potenza Centrale - Castel Lagopesole				
Column	**Coordinates**	**Type of Signal**	**Description**	**Distance Between 2 Consecutive Signals**
1	**118329**	**Station**	**Potenza Centrale**	**0**
2	118329	MS	Main Signal	0
3	115570	AS	Advance Signal	2759
4	114570	MS	Main Signal	1000
5	**114520**	**Station**	**Potenza Superiore**	**50**
6	114520	MS	Main Signal	0
7	109569	AS	Advance Signal	4951
8	108569	MS	Main Signal	1000
9	108519	LC	Level Crossing	50
10	107863	LC	Level Crossing	656
11	106998	LC	Level Crossing	865
12	106610	LC	Level Crossing	388
13	106351	AS	Advance Signal	259
14	105351	MS	Main Signal	1000
15	105301	LC	Level Crossing	50

16	104736	LC	Level Crossing	565
17	**104320**	**Station**	**Avigliano**	**416**
18	104320	MS	Main Signal	0
19	104025	LC	Level Crossing	295
20	100765	AS	Advance Signal	3260
21	99765	MS	Main Signal	1000
22	**99715**	**Station**	**Pietragalla**	**50**
23	99715	AS	Advance Signal	0
24	98599	MS	Main Signal	1116
25	98549	LC	Level Crossing	50
26	95518	AS	Advance Signal	3031
27	94518	MS	Main Signal	1000
28	**94468**	**Station**	**Castle Lagopesole**	**50**

Double Track

In this case, we should consider about the length of the block sections, which is calculated by the sum of the 4 elements:

- Length of the longest train in the operation at the line.
- Reaction time distance, which the distance train will travel from when the driver of the train sees the sign till He She does the braking.
- Braking distance, which the distance train will travel from when the driver of the train is braking till the train will stop.
- Safety Margin, and it depends to the assumption of the designer, who has to consider to many factors, like slope of the line, the weather situation of the area, the braking system of the operating trains and…

1. First, we should consider about the length of the trains and select the longest one, there is 2 types of the trains are operating in this line, the first one is the diesel train-set DMU Class 150, which has the total mass of 76.4 ton and the length of the 60 m and the other one is the electric train-set TAF, which has the total mass of 273 ton and the length of 104 m, so we should choose the longest train which is the electric train-set TAF with 104 m length.

   $L_t = 104\ [m]$

2. Second, the reaction distance should be considered, in this case the reaction time of the driver is assumed 2 seconds, so this time should be multiplied to the maximum speed of the train, which has the highest speed in the line, and the maximum speed in operation in this line is 105 (km/h).

   $L_r = 2 * (105/3.6)$

   $L_r = 59\ [m]$

3. Third, the braking distance should be calculated, which is related to the braking system and deceleration and speed of the train, however the deceleration of the train should be a value which is acceptable and does not have any effect of the comfort of the passengers, so I assumed 0.8 [m/s^2] which is an acceptable and reasonable value for deceleration.

   $L_b = v^2/2a$

   $L_b = 30^2/(2*0.8)$

   $L_b = 563\ [m]$

4. Forth, the last part of this distance, which is a safety margin, and 100 m is assumed for this safety margin.

   $Ls = 100\ [m]$

The block section should be higher or equal than the sum of the all these distances.

$Db \geq Lt + Lr + Lb + Ls$

$Db \geq 104 + 59 + 563 + 100$

$Db \geq 826\ [m]$

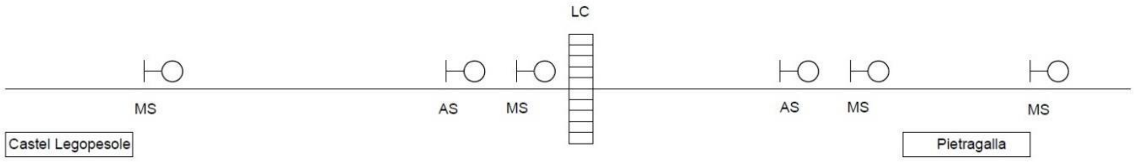
But in this case I assume the two block sections, because if I assume just one block section in this case the following train always will face the yellow light and always it should be reduce the speed and cannot do the best performance of its own, but I assume the two block sections in this case the following train always will see the green light and can do the best performance on the line, so the distance between trains should be [2 * 826 m = 1652 m]

Castel Lagopesole - Potenza Centrale				
Column	**Coordinates**	**Type of Signal**	**Description**	**Distance Between 2 Consecutive Signals**
1	**94468**	**Station**	**Castle Lagopesole**	**0**
2	94468	MS	Main Signal	0
3	95294	MS	Main Signal	826
4	96120	MS	Main Signal	826
5	96946	MS	Main Signal	826
6	97772	MS	Main Signal	826
7	98549	LC	Level Crossing	777
8	99375	MS	Main Signal	826
9	**99715**	**Station**	**Pietragalla**	**340**
10	99715	MS	Main Signal	0
11	100541	MS	Main Signal	826
12	101367	MS	Main Signal	826
13	102193	MS	Main Signal	826
14	103019	MS	Main Signal	826
15	104025	LC	Level Crossing	1006
16	**104320**	**Station**	**Avigliano**	**295**
17	104320	MS	Main Signal	0
18	104736	LC	Level Crossing	416
19	105301	LC	Level Crossing	565
20	106127	MS	Main Signal	826
21	106610	LC	Level Crossing	483
22	106998	LC	Level Crossing	388
23	107863	LC	Level Crossing	865
24	108519	LC	Level Crossing	656
25	109345	MS	Main Signal	826
26	110171	MS	Main Signal	826
27	110997	MS	Main Signal	826
28	111823	MS	Main Signal	826
29	112649	MS	Main Signal	826
30	113475	MS	Main Signal	826
31	**114520**	**Station**	**Potenza Superiore**	**1045**
32	114520	MS	Main Signal	0
33	115346	MS	Main Signal	826
34	116172	MS	Main Signal	826
35	116998	MS	Main Signal	826
36	117824	MS	Main Signal	826

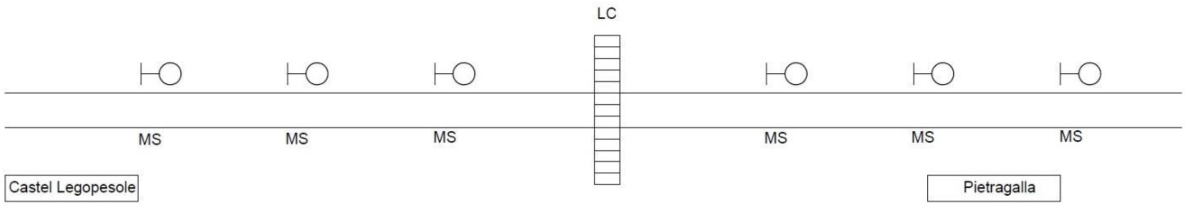
37	**118329**	**Station**	**Potenza Centrale**	**505**

Potenza Centrale - Castel Lagopesole				
Column	**Coordinates**	**Type of Signal**	**Description**	**Distance Between 2 Consecutive Signals**
1	**118329**	**Station**	**Potenza Centrale**	**0**
2	118329	MS	Main Signal	0
3	117503	MS	Main Signal	826
4	116677	MS	Main Signal	826
5	115851	MS	Main Signal	826
6	115025	MS	Main Signal	826
7	**114520**	**Station**	**Potenza Superiore**	**505**
8	114520	MS	Main Signal	0
9	113694	MS	Main Signal	826
10	112868	MS	Main Signal	826
11	112042	MS	Main Signal	826
12	111216	MS	Main Signal	826
13	110390	MS	Main Signal	826
14	109564	MS	Main Signal	826
15	108519	LC	Level Crossing	1045
16	107863	LC	Level Crossing	656
17	106998	LC	Level Crossing	865
18	106610	LC	Level Crossing	388
19	105784	MS	Main Signal	826
20	104958	MS	Main Signal	826
21	104736	LC	Level Crossing	222
22	**104320**	**Station**	**Avigliano**	**416**
23	104320	MS	Main Signal	0
24	104025	LC	Level Crossing	295
25	103199	MS	Main Signal	826
26	102373	MS	Main Signal	826
27	101547	MS	Main Signal	826
28	100721	MS	Main Signal	826
29	**99715**	**Station**	**Pietragalla**	**1006**
30	99715	MS	Main Signal	0
31	98889	MS	Main Signal	826
32	98549	LC	Level Crossing	340
33	97723	MS	Main Signal	826
34	96897	MS	Main Signal	826
35	96071	MS	Main Signal	826
36	95245	MS	Main Signal	826
37	**94468**	**Station**	**Castle Lagopesole**	**777**

In the below figure there is the representation of the signalling for a single track of the railway between Castel Lagopesole and Pietragalla stations section, which is the first part of the our railway project, moreover there is a level crossing in the middle of this section, so there is 2 kinds of signals, AS (Advanced Signal) and MS (Main Signal) and by looking to the signals we can understand the direction of the line.



In the below figure there is the representation of the signalling for a double track of the railway between Castel Lagopesole and Pietragalla stations section, which is the first part of the our railway project, moreover there is a level crossing in the middle of this section, so there is just one mode of signal which is MS (Main Signal) and the distance of the signals are 826 m which is calculated in previous pages, however by looking to the signals we can understand the direction of the line.



VI. PROJECT WORK

Minimum headway and capacity calculation by UIC 405 method

For the section from Castel Lagopesole to Potenza Centrale

To calculate the minimum headway between two trains running in the same direction and the bidirectional capacity by using the UIC 405 method for:

1. Single track layout (present scenario)
2. Double track layout (upgrade scenario)

Hypothesis for the calculation: single typology of traffic operated with

- Diesel referenced train
- Electric referenced train

The expression to use for the calculation is: $P = \mathrm{T} \,/\, (t_{fm}+t_r+t_{zu})$

where

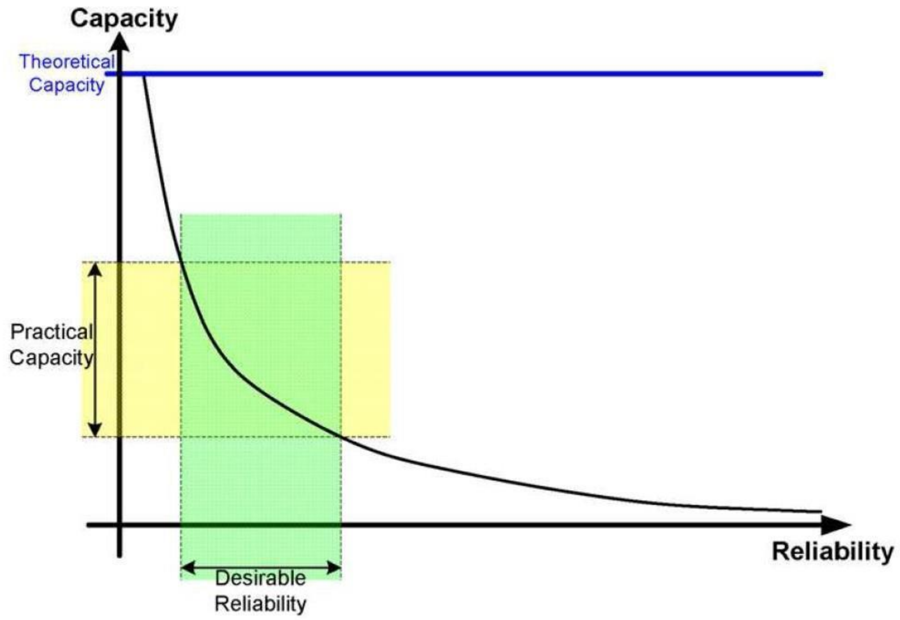
T – Reference time
t – Minimum headway f_m
t_r = Buffer Time

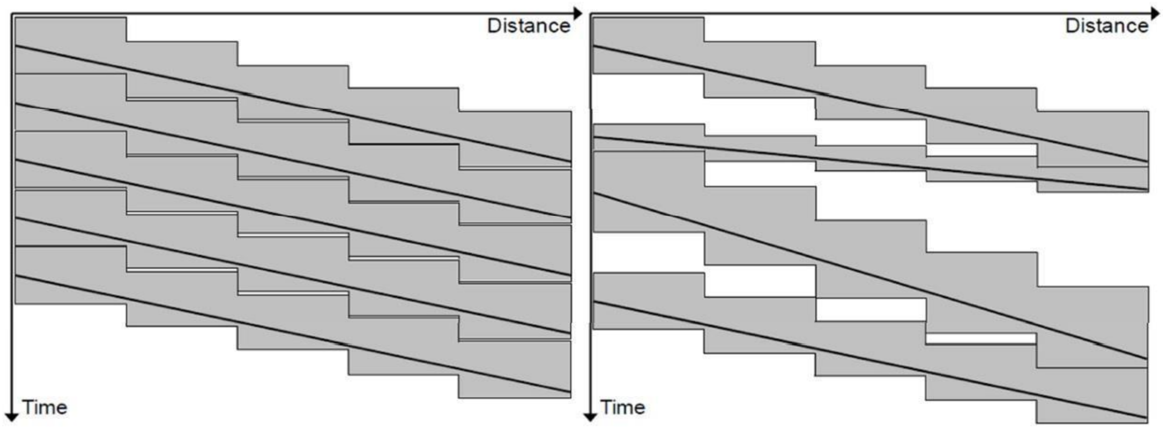
t_{zu} = additional time, taking into account the number (a) of intermediate block sections on the double track critical line section calculated as

$t_{zu} = [\ 0.25 * a\ ]$

We have different types of the capacities:

1. **Theoretical Capacity** is the number of trains that could run over a route, during a specific time interval, mathematically calculated using an empirical formula. It represents an upper limit for line capacity.
2. **Practical Capacity** represents the practical limit of the number of trains (usually considering the current train mix, priorities, traffic bunching, etc.) that van be moved on a line in order to guarantee a reasonable level of reliability (see next figure). It is a more realistic measure than theoretical capacity, usually around 60 – 70 % of the latter.
3. **Used Capacity** is the actual traffic volume over the network, usually lower than the practical capacity.
4. **Available Capacity** is the difference between the used capacity and the practical capacity and provides and useful indication of additional trains that could be handled by the network.





<u>Capacity calculation by UIC methods</u>

- Probabilistic methods issued in 1978 (Leaflet 405-1 R) and 2004 (Leaflet 406 R)
- User-Friendliness
- Capability to take into account:
    - Trains already running on line
    - Operation quality requirements
    - Infrastructural and technological peculiarities of line
- Usability in infrastructure planning phase.

In this case, there is many ways to calculate the capacity of the line, but the UIC 405 method is assumed and this is one of the simplest methods for calculating the headway and capacity of the line.

First, the T, which is the referenced time is considered to 3 hours.

Second, the t_{fm} , which is the average minimum headway calculation (by UIC 405), and it is calculated by this formula;

$$t_{fm} = T_{ot} / (N - 1)$$

where

T_{ot} – is the total infrastructure occupation time, which is calculated by the summation of the Matrix[S*O]

N – is the number of all running trains.

After the designing the signals, which is done in the previous project work, in both case of Single track and Double track. The following step is the calculation of the capacity of the line. For calculating the capacity of the line there are several methodologies, but for this project work the UIC method is chosen. The reference paper is the Finche 405-1R of the 1978. It's used because of it is the simplest method and it is good also for the project phase.

We know the equation of the capacity from the UIC method.

The T, which is the reference time is in this project work is 3 hours.

The t_{fm} is the average minimum headway between trains, which is calculating by division of the total occupation time to total amount of the running trains minus one.

From the previous project works we know the Occupation time by 1 train is represented in the below table.

Total Running Time Between 5 Stations in both directions [min]			
Trainset	**Model**	**Castel Lagopesole to Potenza Centrale**	**Potenza Centrale to Castel Lagopesole**
DMU Class 150	**DIESEL**	20	19
TAF	**ELECTRIC**	19	18

The next, we should calculate the elapsing time, which is calculated from the queuing theory, so in the queuing theory we have 2 important elements, first λ, which is the arrival rate, and it is equal to:

$$\lambda = 1 / (t_{fm} + t_r) \text{ (Arrival Rate)}$$

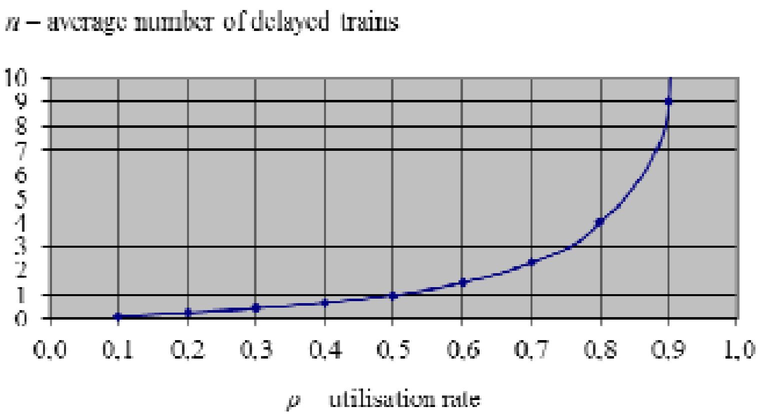
The second elements we should consider about that in queuing theory is Serving rate, which is represented by μ which is equal to:

$$\mu = 1 / (t_{fm}) \text{ (Serving Rate)}$$

The final result of the queuing theory is the ρ, which is Utilization Rate, which is equal to:

$$\rho = \lambda / \mu$$

In this project work by looking to the below graph, because of High traffic density condition, the utilization rate is assumed 0.75 and the n is assumed 3, so the result is this: $t = 0.33 * t_{fm}$



The final results of the all calculations are reported in the below tables

Single Track			
DMU 150 Diesel Trainset		**DMU 150 Diesel Trainset**	
Castel Lagopesole to Potenza Centrale		**Potenza Centrale to Castel Lagopesole**	
No. of Trains	6	No. of Trains	6
T_{fm} [sec]	1440	T_{fm} [sec]	1368
T_r [sec]	475.2	T_r [sec]	451.44
T_{zu} [sec]	0	T_{zu} [sec]	0
Occupation Time [sec]	7200	Occupation Time [sec]	6840
T [sec]	10800	T [sec]	10800
Capacity [Train/3 hrs]	5.64	Capacity [Train/3 hrs]	5.94
Single Track			
TAF Electric Trainset		**TAF Electric Trainset**	
Castel Lagopesole to Potenza Centrale		**Potenza Centrale to Castel Lagopesole**	
No. of Trains	6	No. of Trains	6
T_{fm} [sec]	1404	T_{fm} [sec]	1332
T_r [sec]	463.32	T_r [sec]	439.56

T_{zu} [sec]	0	T_{zu} [sec]	0
Occupation Time [sec]	7020	Occupation Time [sec]	6660
T [sec]	10800	T [sec]	10800
Capacity [Train/3 hrs]	5.78	Capacity [Train/3 hrs]	6.10

Double Track			
DMU 150 Diesel Trainset		**DMU 150 Diesel Trainset**	
Castel Lagopesole to Potenza Centrale		**Potenza Centrale to Castel Lagopesole**	
T_{fm} [sec]	278	T_{fm} [sec]	301
T_r [sec]	91.74	T_r [sec]	99.33
T_{zu} [sec]	3	T_{zu} [sec]	3
T [sec]	10800	T [sec]	10800
Capacity [Train/3 hrs]	28.90	Capacity [Train/3 hrs]	26.70

Double Track			
TAF Electric Trainset		**TAF Electric Trainset**	
Castel Lagopesole to Potenza Centrale		**Potenza Centrale to Castel Lagopesole**	
T_{fm} [sec]	254	T_{fm} [sec]	281
T_r [sec]	83.32	T_r [sec]	92.73
T_{zu} [sec]	3	T_{zu} [sec]	3
T [sec]	10800	T [sec]	10800
Capacity [Train/3 hrs]	31.60	Capacity [Train/3 hrs]	28.60

For the both directions and for the both types of the trains the peak period is considered in calculations.

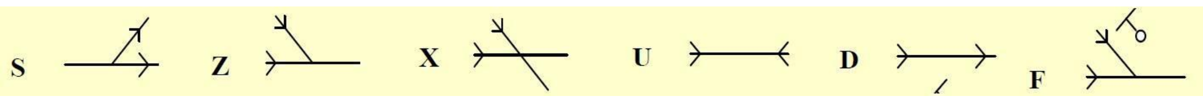
VII. PROJECT WORK

Station routes schematization, occupation and interdiction times calculation

To draw a simplified schematic layout of Potenza Centrale station and the corresponding Muller figure. To identify the routes allowed by the layout:

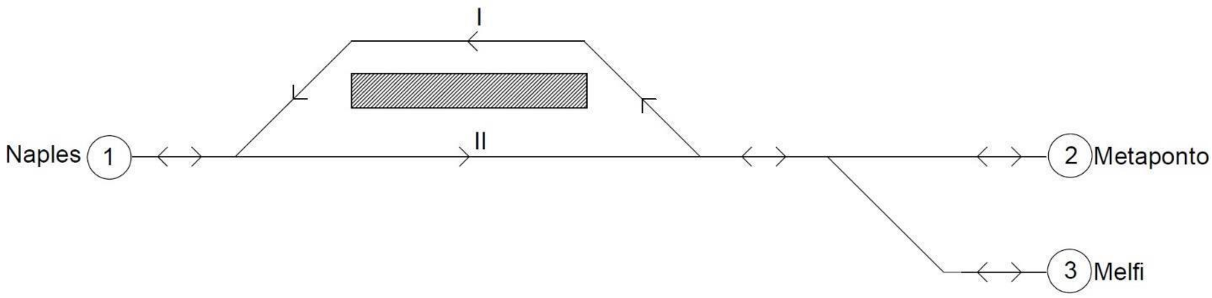
- Entering routes: main protection signal – main departure signals;
- Exiting routes: main departure signal – last switch along the exiting route.

To compile the matrix of routes including the following typologies of incompatibility:



To build up graph of routes, matrix of n-tuples and traffic solutions tree:

To build up occupation/interdiction times matrix taking into account the following data:



- Each train stops in the station and departs after the stop;
- Entering trains running on deviated switches must start their deceleration to the speed allowed by the switch in correspondence of main protection signals;
- Exiting trains running on deviated switches must run at least up to a distance corresponding to train's length at a speed lower than that allowed by the switch;
- Stop time for all trains: 60 s;
- Routes preparation and waiting times: 90 s for entering routes and 60 s for exiting route;
- Maximum speed on switches: 30 [km/hr] (deviated) and 60 [km/hr] (direct)

The Potenza Centrale Station, formerly known as Potenza Inferiore, is the main station serving the city and commune of Potenza, in the region of Basilicata, Southern Italy. Opened in 1880, it forms part of the Battipaglia-Potenza_Metaponto railway and is also a junction of a branch line to Foggia.

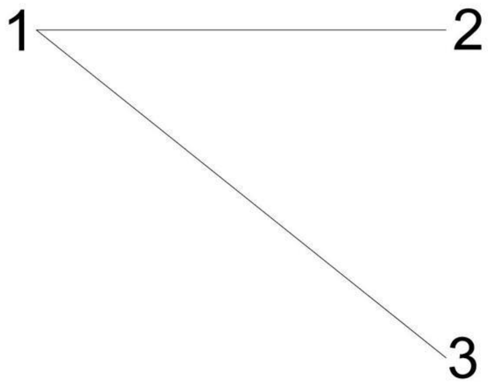
The station has about 950,000 passenger movements each year.

Some of trains that stop at the station provide long distance links with major cities such as Rome and Naples, and also with the region of Apulia. The more common regional trains link Potenza with closer destination, including Salerno, Naples, Melfi, Foggia and Taranto.

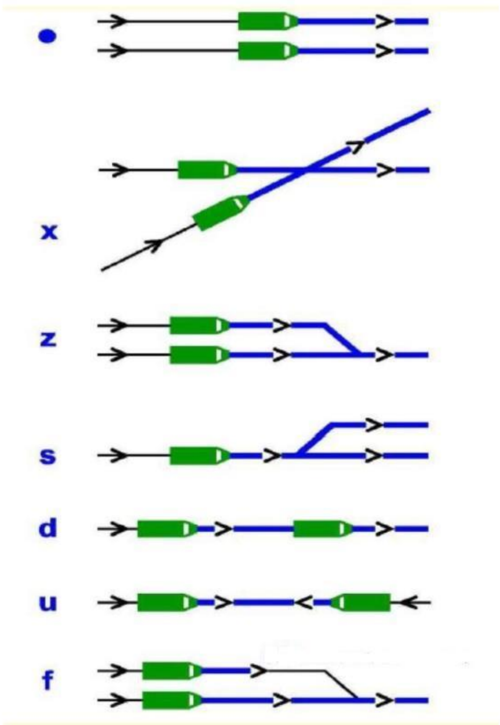
The station is served by the following services:

- Intercity Services Rome – Naples – Salerno – Taranto
- Regionale Services Naples – Salerno – Potenza – Metaponto – Taranto
- Regionale Services Foggia – Melfi – Potenza

In the station three lines converge and the station works as a terminus and as a transit, linking different destinations, which is represented at above figures, there are 1 platform. Now with respect to this information, we can draw the Muller figure of the station, which is represented in below graph.
Now we should figure out the (n X n) Matrix, which is representing the all routes with compatibilities and incompatibilities, and we know this matrix is a symmetric matrix, so if we can write just one rectangle part of that it is enough;



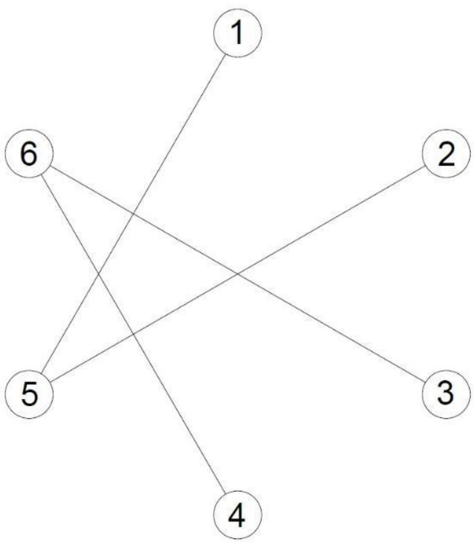
In this station there are 6 routes with all combinations, so the matrix should be (6 X 6)



Routes	Origin Node	Destination Node	Line
1	Metaponto	Potenza Station	I
2	Melfi	Potenza Station	I
3	Potenza Station	Metaponto	II
4	Potenza Station	Melfi	II
5	Naples	Potenza Station	II
6	Potenza Station	Naples	I

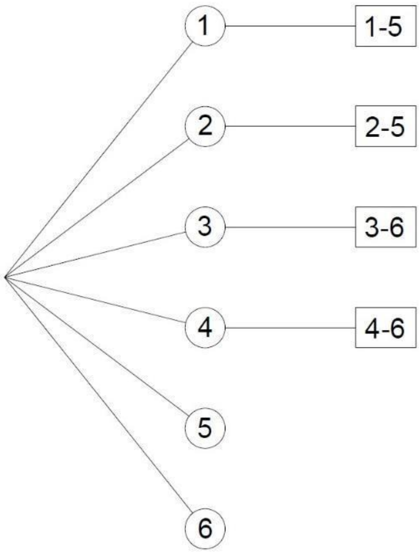
		1	2	3	4	5	6
		2-I	3-I	II-2	II-3	1-II	I-1
1	2-I	a	z	u	u	c	d
2	3-I		a	u	u	c	d
3	II-2			a	d	d	c
4	II-3				a	d	c
5	1-II					a	u
6	I-1						a

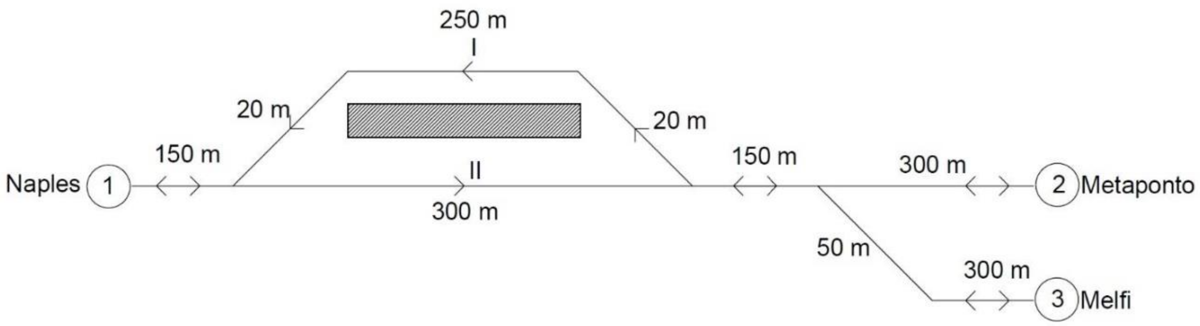
Now with respect to this picture the solution tree is possible to drawn, so the solution tree that represents all the comparisons is drawn in the below graph:



	1	2	3	4	5	6
1_5	..	..	..	..	..	xx

2_5	..	..	..	..	..	xx
3_6	..	..	..	..	..	..
4_6	..	..	..	..	..	..





Occupation Time Matrix for Potenza Centrale Train Station						
Type	**Arrival**		**Departures**		**Arrival**	**Departure**
Number	1	2	3	4	5	6
Routes	2-I	3-I	II-2	II-3	1-II	I-1
Time [s]	371	395	330	396	315	323

Occupation/Interdiction Time Matrix for Potenza Centrale Train Station

Type			Arrival		Departures		Arrival	Departure
Number			1	2	3	4	5	6
Routes			2-I	3-I	II-2	II-3	1-II	I-1
Arrival	1	2-I	371	395	330	360	0	323
	2	3-I	371	395	294	396	0	270
Departures	3	II-2	126	150	330	180	315	0
	4	II-3	126	150	294	396	315	0
Arrival	5	1-II	0	0	276	276	315	323
Departure	6	I-1	371	395	0	0	126	323

VIII. PROJECT WORK

Traffic Assignment and station capacity calculation For Potenza Centrale station

1. To formulate an operational plan, by assigning flows of trains to routes, balanced by lines and directions, starting from the traffic hypothesis adopted for the line.
2. To calculate regular and total utilization rates by the following formulations (Potthoff method)

$$C_{reg.util.} = \frac{B}{T}$$

$$C_{ut.tot.} = \frac{B + \frac{\sum Rij}{n}}{T}$$

3. To increase the balanced flows by route, in order to check the corresponding variations of the utilization rates to finally reach the capacity of the station, according to thresholds of utilization rates to be fixed

First of all, after calculation the occupation and interdiction matrix now we should calculate the capacity of the Potenza Centrale station according to the Potthoff Method, which is assuming that all the lines are balanced (there are the same number of trains per hour) are running on these lines, so by considering this method we can calculate the capacity of a station with or without the considering the delays of the trains:
If we want to consider the delay, we should use this formula:

$$U_R = \frac{B}{T}$$

Which is called Regular Utilization Coefficient, and we are just considering the occupation and interdiction time divided to the reference time, and this is more theoretical and not practical and we cannot consider this in reality.
If we want to consider also the delays of the trains, we should use this formula:

$$U_T = \frac{B + \frac{\sum Rij}{n}}{T}$$

Which is called Global Utilization Coefficient, and we are considering the occupation and interdiction time plus the average of the sum of the all delays, over the reference time, and this is more practical and we can use this in reality, and the Global Utilization Coefficient is always higher than Regular Utilization Coefficient.

For solving this exercise, I assumed each hour these are 2 trains and the reference time is 24 hours (1 Day)
N = Total Number of trains which are running in the reference time
N = 48
T = 24 hours
For calculating the nm we have 2 approaches:

1. Exact Calculation – In this method first we are considering the n-tuples of the compatible routes excluding all others, routes used with same frequency, as many times

as it appears during the reference time, and in this case, we are considering the operational condition which is with maximum utilization.

$$nm = \frac{(4*2)+(1*2)}{6} = 1.666$$

2. Empirical calculation – In this method we are considering each route is used by a single train during the reference time, and in this case, the worst condition is when all the routes are incompatible, so in this case the nm is equal to 1, however the best condition is when all the routes are compatible, so in this case nm is equal to number of routes, and always the result of this method is lower than the exact calculation method.

$$nm = \frac{Cells\ of\ Matrix}{Cells\ with\ incompatabilities} = \frac{36}{38} = 1.285$$

Now we can create the (n_i X n_j) Matrix, which is representing all the trains running on our lines, without considering the compatible and incompatibility of our lines.

(n_i * n_j) Matrix									
Type				**Arrival**		**Departures**		**Arrival**	**Departure**
Number of Trains				2	2	2	2	2	2
Number				1	2	3	4	5	6
Routes				2-I	3-I	II-2	II-3	1-II	I-1
Arrival	2	1	2-I	4	4	4	4	4	4
	2	2	3-I	4	4	4	4	4	4
Departures	2	3	II-2	4	4	4	4	4	4
	2	4	II-3	4	4	4	4	4	4
Arrival	2	5	1-II	4	4	4	4	4	4
Departure	2	6	I-1	4	4	4	4	4	4

In below table the occupation/interdiction time is represented in seconds and in the next one the same one is represented in minutes.

Occupation/Interdiction Time Matrix for Potenza Centrale Train Station (in Min)								
Type			**Arrival**		**Departures**		**Arrival**	**Departure**
Number			1	2	3	4	5	6
Routes			2-I	3-I	II-2	II-3	1-II	I-1
Arrival	1	2-I	0.951	1.013	0.846	0.923	0.000	0.828
	2	3-I	0.951	1.013	0.754	1.015	0.000	0.692
Departures	3	II-2	0.323	0.385	0.754	0.462	0.808	0.000
	4	II-3	0.323	0.385	0.754	0.708	0.808	0.000
Arrival	5	1-II	0.000	0.000	0.708	0.708	0.808	0.828
Departure	6	I-1	0.951	1.013	0.000	0.000	0.323	0.828

After finding the Occupation/Interdiction time matrix now we should calculate the (n_i * n_j * t_{ij}) Matrix, which is represented in below table.

(n_i * n_j) Matrix								
Type			**Arrival**		**Departures**		**Arrival**	**Departure**
Number of Trains			1	2	3	4	5	6

Routes			2-I	3-I	II-2	II-3	1-II	I-1
Arrival	1	2-I	0.0	26.3	22.0	24.0	0.0	21.5
	2	3-I	24.7	0.0	19.6	26.4	0.0	18.0
Departures	3	II-2	8.4	10.0	0.0	12.0	21.0	0.0
	4	II-3	8.4	10.0	19.6	0.0	21.0	0.0
Arrival	5	1-II	0.0	0.0	18.4	18.4	0.0	21.5
Departure	6	I-1	24.7	26.3	0.0	0.0	8.4	0.0

Now with using the expected delay formula we can calculate the R_{ij} Matrix, which is represented in below table.

$$R_{ij} = \frac{ni * nj * tij^2}{2*T}$$

Expected Delays (R_{ij}) Matrix (sec)								
Type			Arrival		Departures		Arrival	Departure
Number			1	2	3	4	5	6
Routes			2-I	3-I	II-2	II-3	1-II	I-1
Arrival	1	2-I	0.0	28.9	20.2	24.0	0.0	19.3
	2	3-I	25.5	0.0	16.0	29.0	0.0	13.5
Departures	3	II-2	2.9	4.2	0.0	6.0	18.4	0.0
	4	II-3	2.9	4.2	16.0	0.0	18.4	0.0
Arrival	5	1-II	0.0	0.0	14.1	14.1	0.0	19.3
Departure	6	I-1	25.5	28.9	0.0	0.0	2.9	0.0

So, now we can identify all the parameters of the related to the capacity of the station:

$$tm = \frac{\sum ni * nj * tij}{\sum ni * nj} = \frac{410.8}{144} = 2.852$$

$$\frac{\sum Rij}{n} = \frac{354.24}{1.285} = 275.67$$

$$\frac{\sum Rij}{n} = \frac{275.67}{60} = 4.594$$

$$B = \frac{N}{n} * t = \frac{12}{1.285} * 2.852 = 26.63$$

$$B + \frac{\sum Rij}{n} = 26.63 + 4.594 = 31.220$$

$$U_R = \frac{B}{T} = \frac{26.63}{180} = 0.147$$

$$U_T = \frac{B + \frac{\sum Rij}{n}}{T} = \frac{31.22}{180} = 0.173$$

So, by looking these values we can understand we are using the 17 percent of this station's capacity, and we can increase the number of trains, but we have to consider about the delays and punctuality of the timetable.