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Optimal location of security devices (in a railway infrastructure)

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METRIP
METhodological Tools for Railway Infrastructure Protection

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Summary of the presentation

- **Introduction about RIS and device location**
- **Project METRIP**
- **Covering Problems**
  - **Area Definition:**
    - *Demand points and possible locations*
  - **Visibility and Coverage Analysis:**
    - *Building of the coverage matrix*
- **Covering Models**
  - **Minimizing the number of control devices**
    - *Set Covering Problem (SCP)*
    - *Weighted Demand Covering Problem (WDCP)*
  - **Maximizing the covered demand**
    - *Maximal Covering Problem (MCP)*
    - *Back-up Covering Problem (BCP)*
- **Applications of the Models to test cases**

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Protection of RIS

Data provided by Mineta Transportation Institute's /National Transportation Security Center (MTI/NTSC) From 1970 to 2011, 2.927 attacks against public transportation systems were committed. 48% on buses, 43% against Railway Infrastructure Systems (RIS). RIS attacks are in general more lethal (Madrid 2004, London 2005, Mumbai 2008)

A RIS has a great appeal on assailants for vulnerability and difficulties in guaranteeing its protection:

- open infrastructures;
- high passenger density;
- difficulty in passengers' screening and identification;
- hazardous materials on the lines;
- extent of the infrastructures inside the city;
- economic and social relevance of the railway transportation system.

For all these reasons prevention and preparedness to risks in RIS requires:

- proper analysis of the vulnerabilities of the system;
- clear awareness of criticalities and possible countermeasures;
- adequate methods to design, scale and optimize the protection.

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Baseline Security System

- A baseline security system (BSS) is usually installed for the protection of an asset, not only a RIS asset, with the aim of preventing malicious intrusions. The BSS system is composed by three main classes of protection devices opportunely integrated:
- *Video Surveillance Devices:* fixed perspective cameras (directional cameras); PTZ (Pan-Tilt-Zoom) cameras; omnidirectional cameras; high resolution cameras (particularly suitable for cameras equipped with video-analysis tool).
- *Access Control Devices:* triple technology volumetric sensors; magnetic contacts; proximity readers; access control systems (ACS2/ACS8); infrared barriers.
- *Audio Surveillance Devices:* microphones; sound cards; sound analyzer server.

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Control device location

- Different types of devices, differing in performances and costs, are available. Generally, the higher is the security level guaranteed by a device, the higher is its cost.
- The placement of some devices, such as for example magnetic contacts, access control systems or sound cards is constrained by their specific use. The placement of other devices, such as cameras, volumetric sensors and microphones, has to be strategically performed.
- A good and strategic placement of these devices could efficiently solve the trade-off between achieving higher security levels and minimizing the cost. Moreover, for some of these devices, in particular for cameras, several constraints have to be taken into account when specific security tasks have to achieved: for intrusion detection, the complete coverage of the asset is required.
- A reliable security system, or a system aimed at performing the movement tracking, requires that points of the asset have to be covered by more than one cameras. The usage of video-analysis algorithms, as face recognition algorithms or, specifically for RIS, yellow line crossing algorithms, requires that camera has to be opportunely positioned with respect to the object and the distance has to be lower than a predefined value in order to guarantee a good quality of the image.

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Sensor placement problem

- This problem is referred to as the sensor placement problem and some optimal covering models can be used in designing the security system of an asset, and specifically of a RIS asset. We will give some hints explaining how these models can be used for the specific tasks just described.
- The sensor placement problem has been widely treated in literature as a set covering problem, where the devices to be located are the security devices, whereas the demand to be satisfied is given by the covering of the set of the points of the region to be controlled.

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METRIP
Methodological Tools for Railway Infrastructure Protection

Metrip is an European Project focalized on these challenging aims.

General objective :

Development of a methodological tool aimed at increasing the protection of a RIS asset, by the following process :

- identifying the most critical and vulnerable assets;
- defining the attack scenarios to be detected for each asset;
- designing the security system in terms of type, number and position of the protection devices;
- evaluating the effectiveness of the security system in terms of asset vulnerability to an attack.

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METRIP
Methodological Tools for Railway Infrastructure Protection

This process could be performed by three main interacting modules:

Unified Modeling Language Module (UMLM), devoted to develop the UML models of the:

- RIS assets (geometry, physical structure and main components);
- attacks against RIS (effects, used mean, main steps of the attack);
- protection devices (technological features and cost of each device).

Optimization Module (OM), devoted to find the optimal location of the security system devices within the asset through integer linear programming (ILP) covering models solved by the optimization software Xpress-MP. The location of the devices is optimized with respect to the covered space of the asset and takes into account its specific geometry.

Vulnerability Analysis Module (VAM), devoted to the vulnerability evaluation of the asset in relation to the kind of attacks and protection devices.

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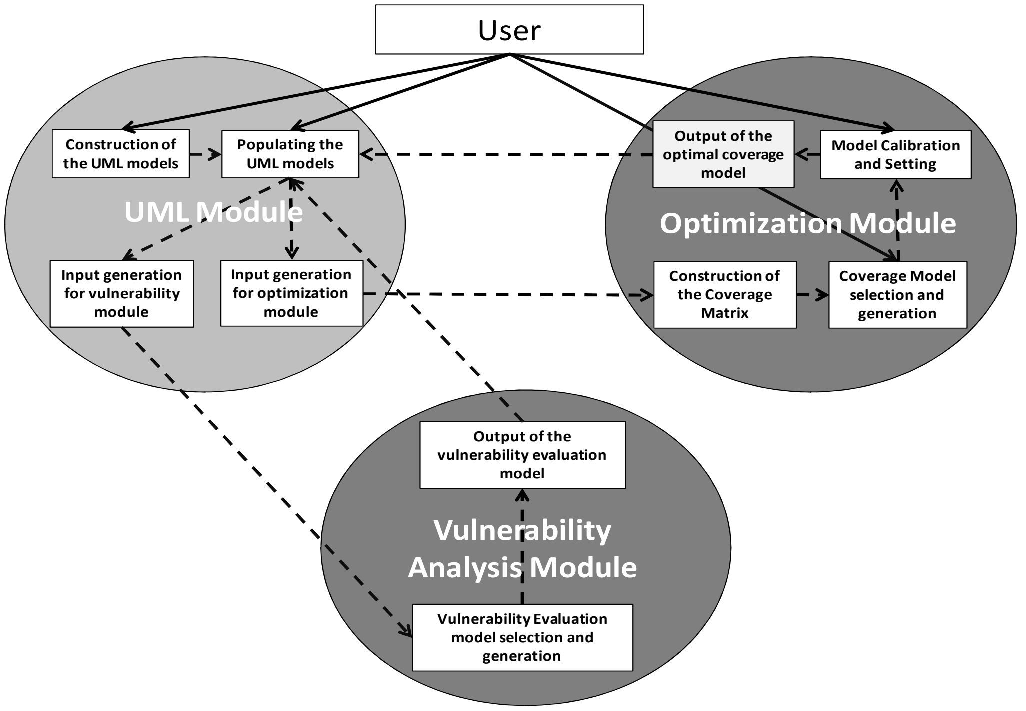
METRIP
Methodological Tools for Railway Infrastructure Protection



The Optimization Module

- The *OM* is devoted to manage a library of ILP covering optimization models used in the design of the security system.
- These models determine the number and the location of most of the control devices which constitute the BSS.
- The *OM* performs the following main activities:
  - Asset discretization.
  - Coverage analysis.
  - Coverage model selection.
  - Solution of the model by an optimization software and generation of the output for the *UMLM*.

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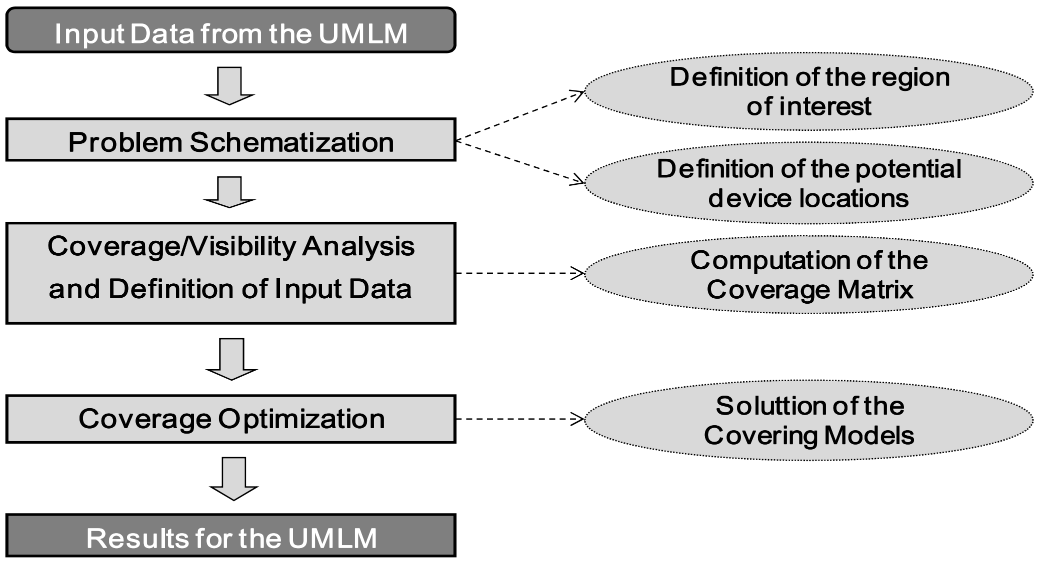
Framework of the OM



The *OM* receives the information related to the assets and protections from the *UMLM*, and returns the solutions of covering models to the *UMLM*.

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Asset discretization

- The area of the asset to be protected has to be made discrete, i.e. we have to pass from the continuous two-dimensional representation to a discrete representation of the asset.

  This operation is performed building a grid with step size k on the plant of the assett. The smaller is the step size of the grid, more detailed is the schematization of the area

- We have to define also the set of points where the devices could be placed, referred to as L. Generally the points sited on the edges and corners of the asset walls and of obstacles.
- In some cases these points have to respect particular conditions. If video-analysis algorithms have to be used, possible location points are the ones which have to be used in order to allow that the algorithms works effectively.
- For example, if we have to locate cameras equipped with video-analysis algorithms for the control of the yellow line crossing, then the camera has to be installed perfectly aligned with the yellow line.

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Coverage analysis

- The activity of a *BSS* device can be schematized through a ***coverage area***, i.e. the portion of area that can be controlled by the device. It is defined by two parameters:

- θ, *coverage angle*, expressed in degrees (0° ÷ 360°), within which the device is active;
- *r*, *coverage ray*, maximum distance (expressed in metres) to which the device is still effective.

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Coverage analysis

- Let us suppose to have a CCTV camera with a 90° coverage angle.
- Given a potential location, the camera can be installed with 4 different orientations which cover 4 different circle sectors, e.g. 0° - 90°, 90° - 180°, 180° - 270, 270° - 360°.
- This means that in a certain point of the set *L* we can locate a single device with a certain orientation, or more devices with different orientations.
- To enlarge the space of the locations, the orientations taken into account for this camera could generate a certain overlapping of the coverage areas. If, for example, the overlap is equal to 45°, we can generate 8 orientations and so 8 different circle sectors: 0° - 90°, 45° - 135°, 90° - 180°, 135° - 225°, 180° - 270, 225° - 315°, 270° - 360°, 315° - 45°.
- To enumerate all the possible orientations for a device located in a point of set *L* we can define a step δ, $\delta \in [0° \div \vartheta]$. For each potential location a device can be located using $n = \lfloor 360°/\delta \rfloor$ different orientations. In this way, it is possible to define, as extension of the set *L* of the potential locations, a set *L'* of potential locations with orientations, $|L'| = n \times |L|$.

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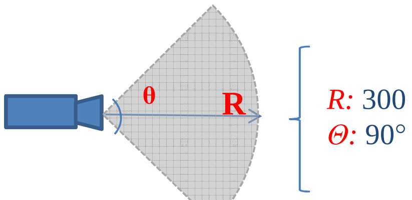
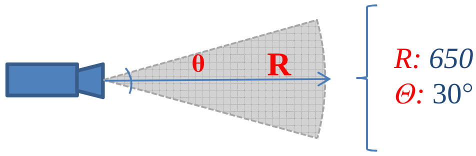
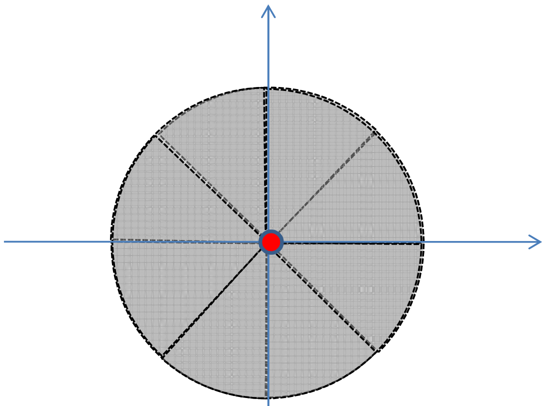
CCTV parameters and orientations



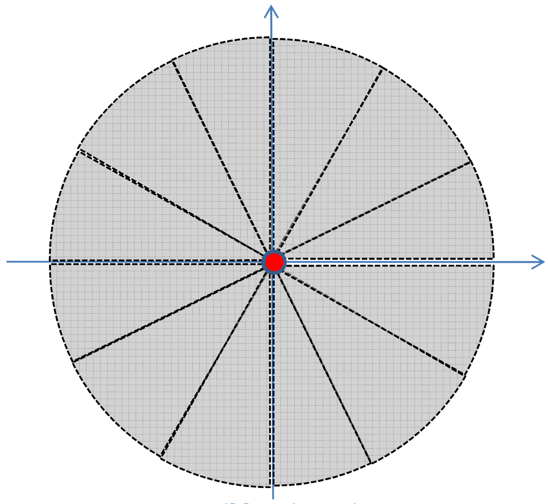


CCTV 1 – 90°



4 possible non overlapping orientations
8 possible overlapping orientations

CCTV 2 – 30°



12 possible orientations

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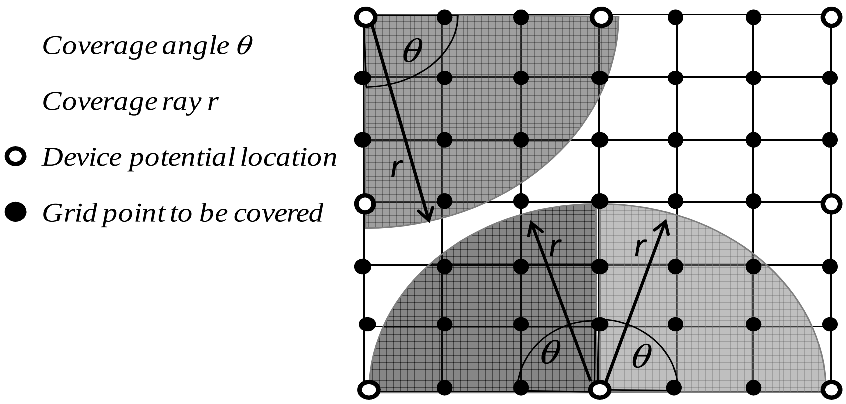
Coverage area



Grid with 49 points and 8 potential locations.

Coverage area and the sub-set *S* of covered points for three devices with a certain orientation.

It is important to underline that:

- a single device could be located in a point with a certain orientation and
- more devices could be located in the same point with different orientations.

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Coverage analysis

- ***Coverage analysis*** consists in determining which are the points of *R* that can be controlled by a device positioned in a potential location with a certain orientation. In the following this set of points will be referred to as *S*, . This operation is made for each potential location of the set *L'* and it can be performed in two ways:

- ***geometrical coverage***: the sub-set *S* for each potential location of a device is built with reference only to the angle and the ray *r* of the coverage area, without taking into account the presence of obstacles in the region of interest.

- ***physical coverage***: the set of points of *S* is filtered considering the presence of obstacles which can interdict the activity of the device. Hence a set $S' \subseteq S$ is generated. This analysis is based on geometric considerations which take into account the coverage area of the device and the shape and the sizes of the obstacle. In this case the set of points *R* to be covered has to be reduced to the set *R'*, which is the union of all the sets *S'*, *S'*= U[*S'*].

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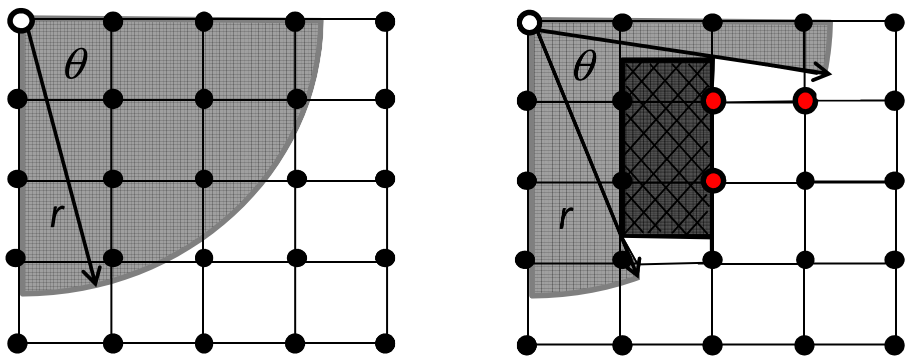
Area of interest and obstacles



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Coverage Matrix

- The coverage analysis allows to generate the so-called *Coverage Matrix* (*CM*), a binary matrix where the rows correspond to the elements of the set , that is to all the potential locations with orientations, and the columns correspond to the points of the set *R*, to cover, so its dimensions are (*n*x|*L*|*,*|*R*|).
- Its generic element c_{ij} is equal to 1 if device i can cover the point j, otherwise it is equal to 0.
- The coverage matrix is the fundamental input for all the covering ILP models used in METRIP.

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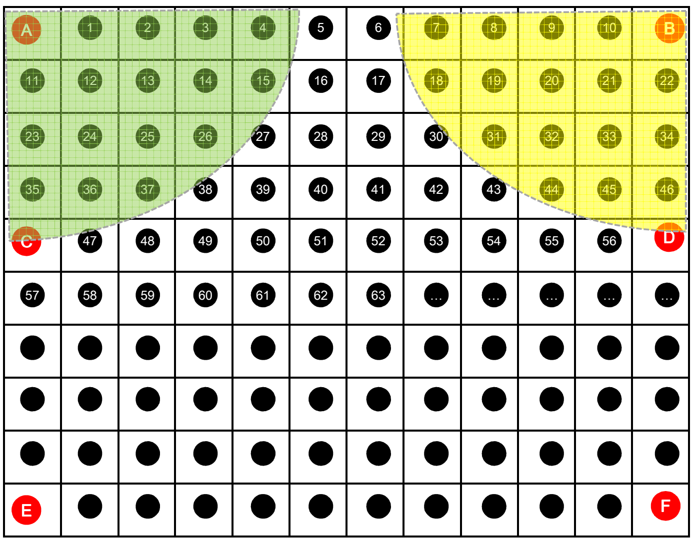
Coverage Matrix



Coverage matrix (only two rows)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
A	1	1	1	1	1						1	1	1	1	1								1	1	1	1	1
B						1	1	1	1	1								1	1	1	1	1					

	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
A											1	1	1	1						1	1						
B			1	1	1	1	1									1	1	1	1								1

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Coverage Model selection

- Covering problems can be classified in function of their objective in two main classes:
  - Minimization of number or total cost of control devices to be located,
  - Maximization of the region covered by the devices.

First class: determine the number of control devices to be located, minimizing the total installation cost and covering all the points of the region of interest or a sub-set of them.

Within the first class we can operate the classification of the points of the region in two groups, *important* and *general* points.

- A point can be classified as important if it is:

  - a potential point used by an attacker for the intrusion (window, doors, fences, etc.);

  - a valuable point of the RIS (control room, vault, etc.)
- An important point have to be compulsorily controlled by video-surveillance system
- If all the points have the same importance, then the problem is referred to as Set Covering Problem (SCP) [9], otherwise it is referred to as Weighted Demand Covering Problem (WDCP).

Second class: determine the position of a prefixed number of control devices in order to maximize primary and/or secondary (back-up) coverage of the region of interest.

In the first case each covered point is covered by a single device (Maximal Covering Problem).

In the second case each covered point could be covered by more than one device (Back-up Covering Problem, BCP). Moreover in these problems the points to be controlled can be weighted or unweighted, depending on the need of assigning them different importance values.

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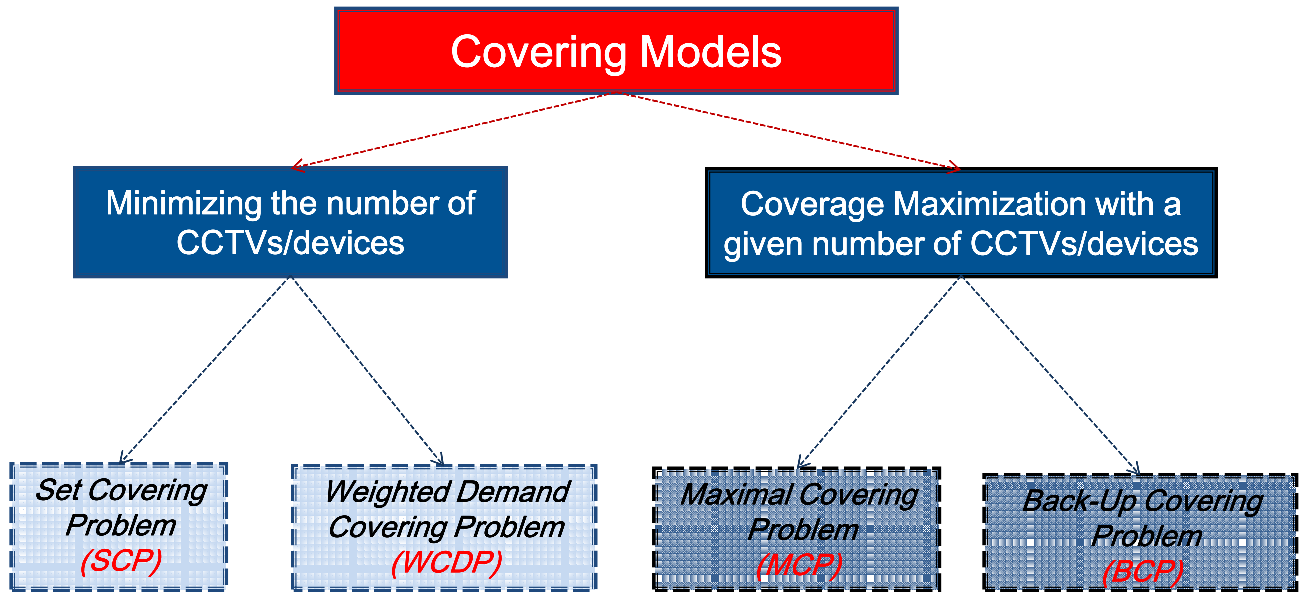
Covering Problems and Models



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Application

Free Open Space

90° CCTV

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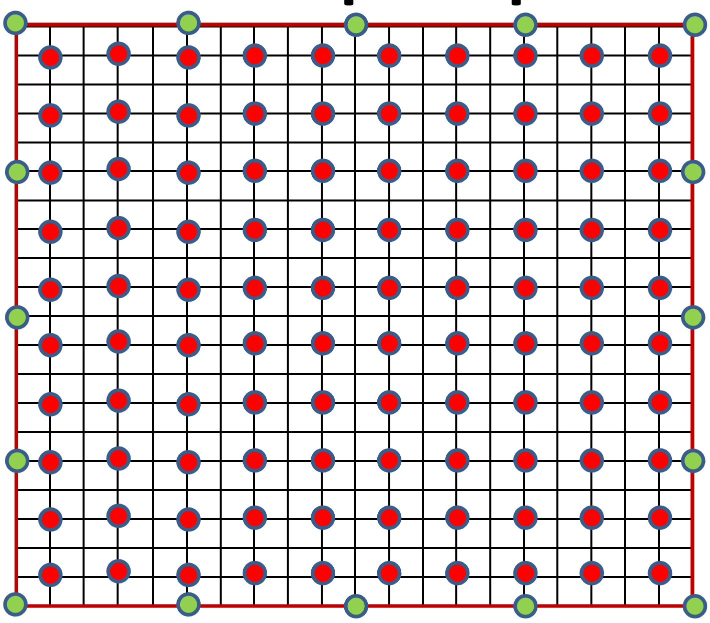
Open Space: case study



Coverage matrix

- 90° CCTV – non overlapping orientations (400x441)
- 90° CCTV – overlapping orientations (800x441)

● (green)	Points of Interest
● (red)	Potential CCTV locations

- Area of Interest: Generic rectangular open space area
- Points to be controlled: Grid of 441 points
- Potential locations: Grid of 100 points (red points)

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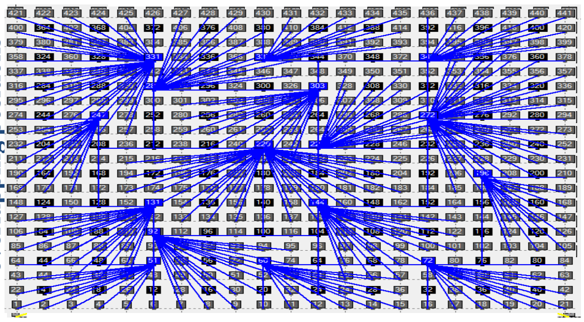
SCP and WDCP application

Covered Point — Uncovered Point — Important points

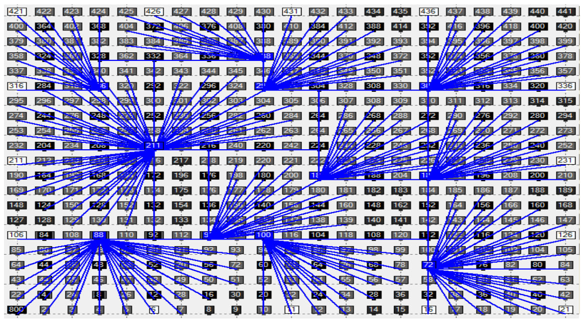
90° CCTV – 4 non overlapping positions

Set Covering Problem



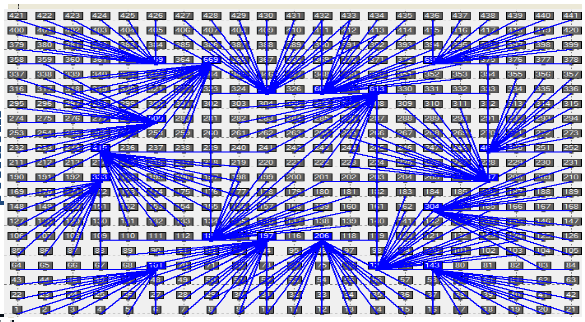
 # CCTV:19 COV100%

Weighted Demand Covering Problem

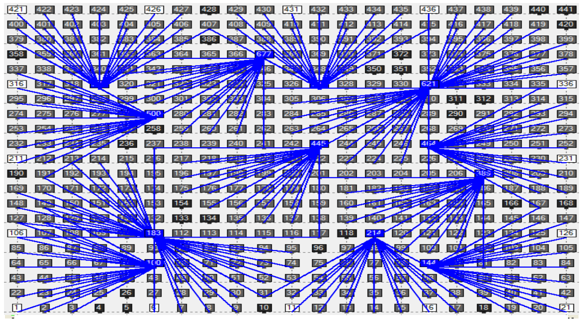


 # CCTV:15 COV 92,74%

90° CCTV – 8 overlapping positions



 # CCTV:18 COV100%



 # CCTV:14 COV 93,88%

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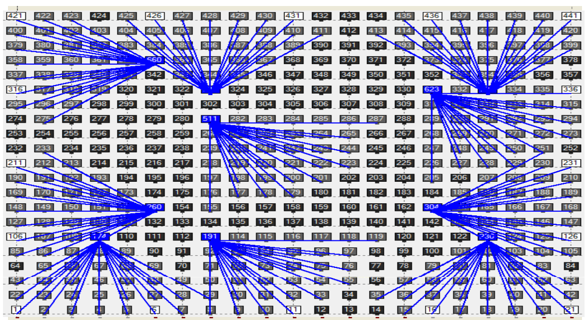
MCP and BCP application

Covered Point — Uncovered Point — B-Covered Point

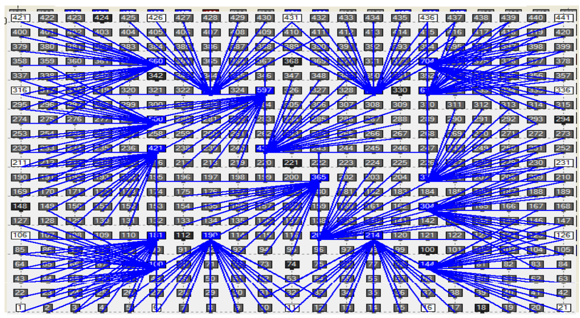
90° CCTV – 8 overlaaping positions

Maximal Covering Problem



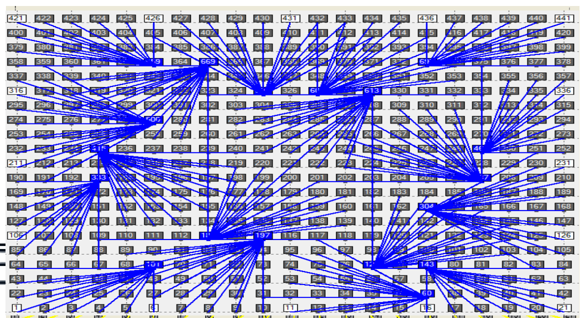
 # CCTV: 10 COV: 75,06%

Back-Up Covering Problem

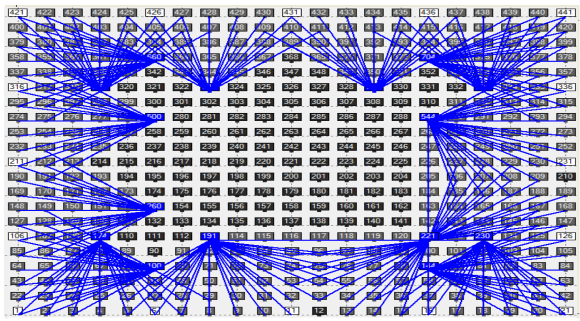


 # CCTV:18 β:0,2 COV:92,74% B-COV:34,47%

90° CCTV – 8 overlaaping positions



 # CCTV:18 COV 100%



 # CCTV:18 β:0,9 COV:70,52% B-COV:53,97%

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Application

Railway Station Sample Scheme

90° CCTV

30° CCTV

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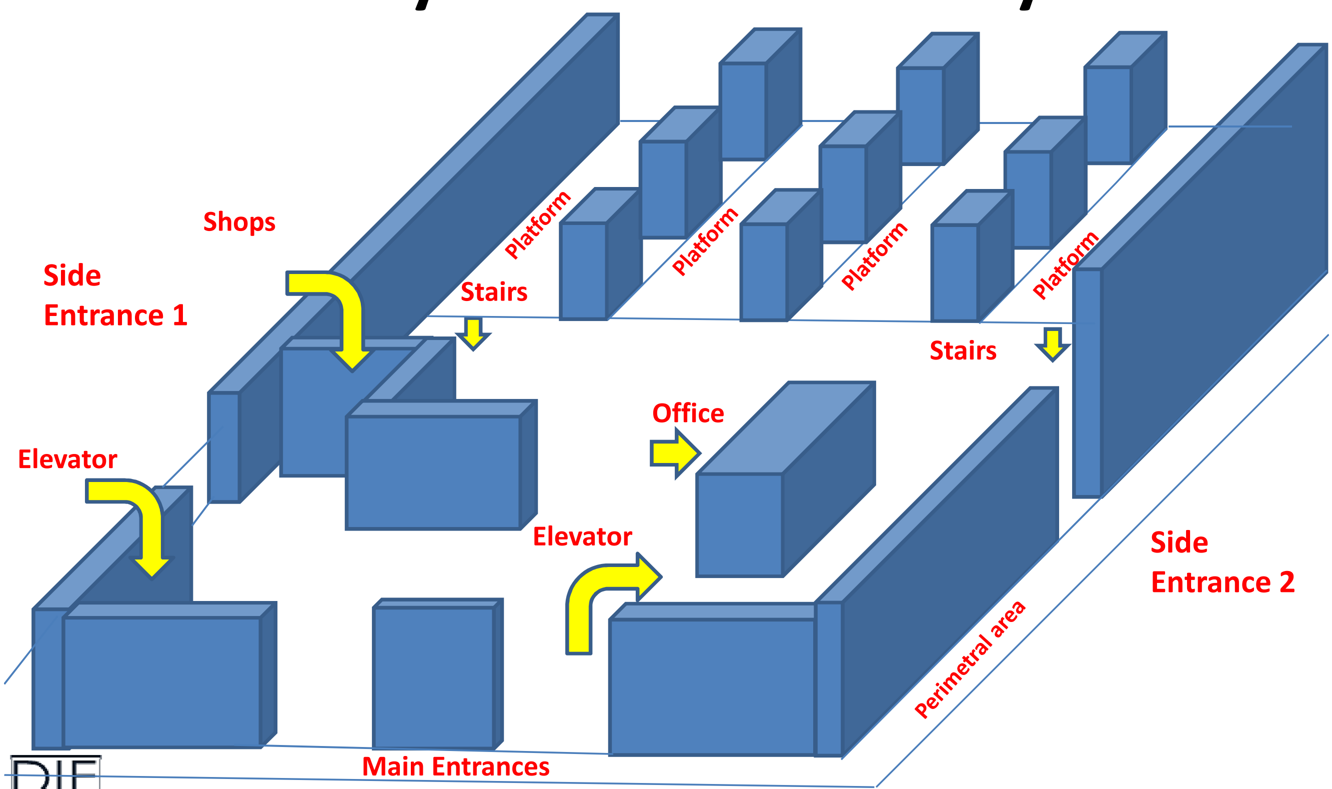
Railway Station: Case Study



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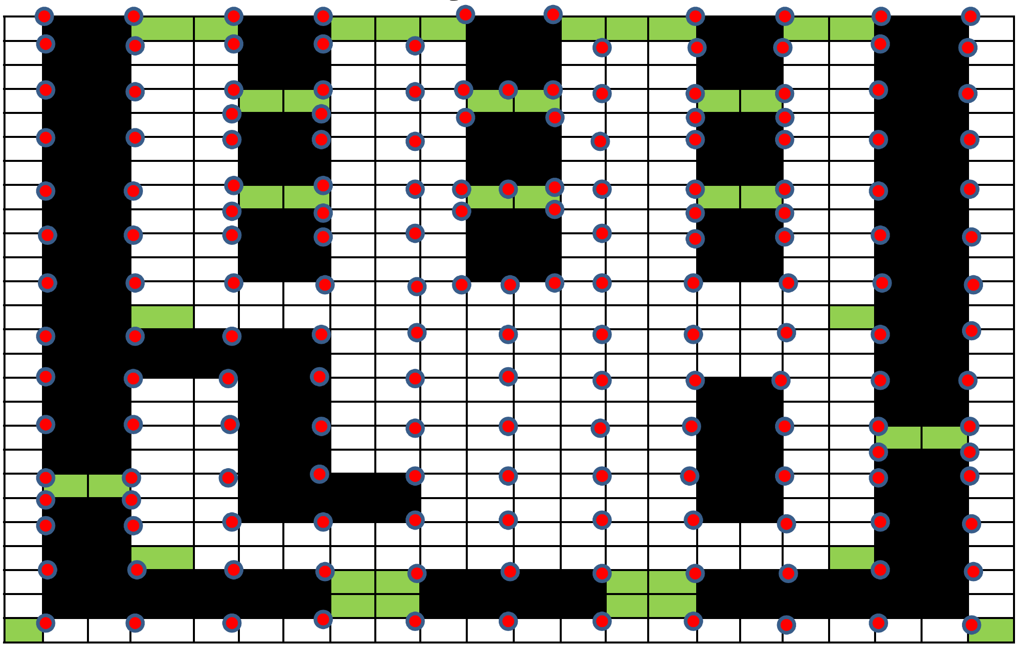
Railway Station: Case Study



Coverage Matrix

- 90° CCTV
8 orientations
(1144x621)

- 30° CCTV
(12 orientations)
(2860x621)

Points of interest

Possible CCTV Locations

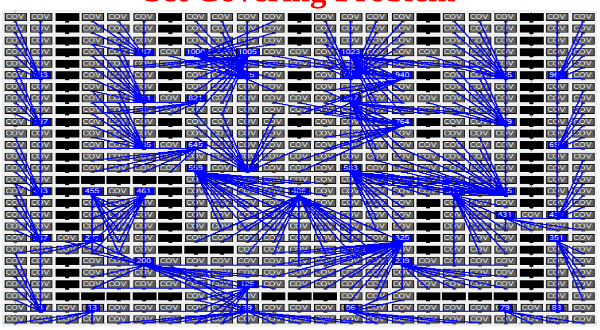
- **Area of interest:** Railway Station Scheme
- **Points to be controlled:** Grid of 621 ponts (526 given the obstacles)
- **Potential locations:** Grid of 143 points

SCP and WDCP solutions

Covered Point | Uncovered Point | Point of interest

Set Covering Problem | **Weighted Demand Covering Problem**

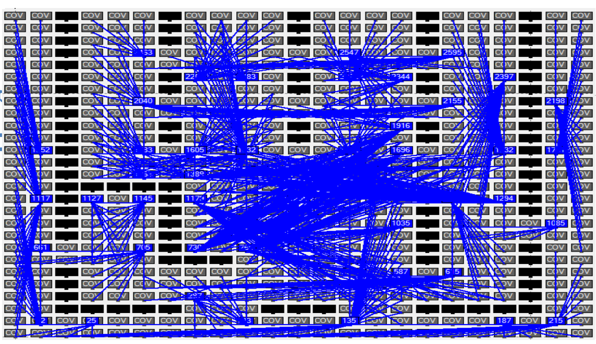
90° - 8 overlapping orientations



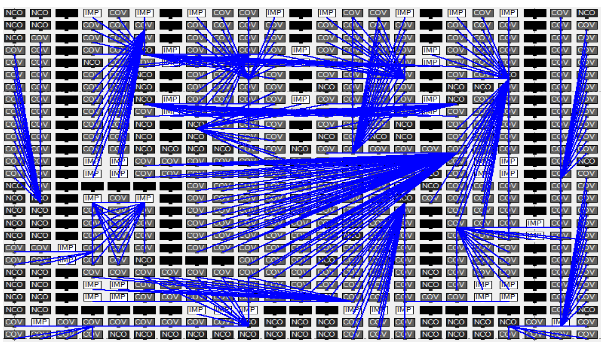
 # CCTV:45 COV: 100%

 # CCTV:26 COV: 69,58%

90° - 8overlapping orientations
30° - 12 non-overlapping orientations



 # CCTV:39 COV: 100%



 # CCTV:28 COV: 85,36%

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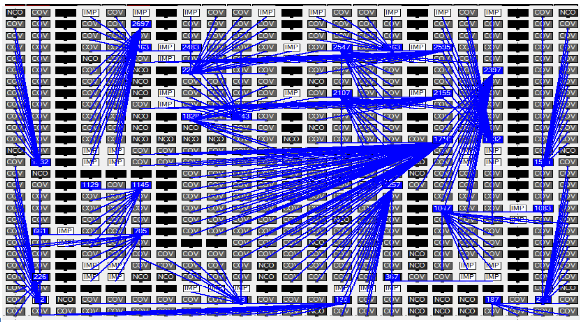
MCP and BCP solutions

Covered Point | Uncovered Point | B-Covered points

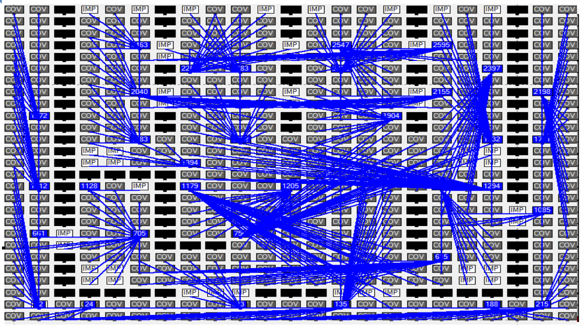
90° - 8overlapping orientations

30° - 12 non-overlapping orientations

Maximal Covering Problem

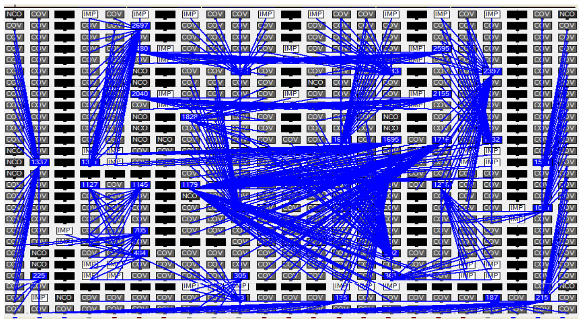


 # CCTV1 +CCTV2: 31 COV 96,67%

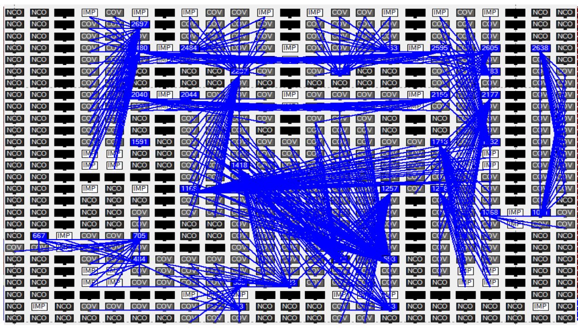


 # CCTV1 +CCTV2 :39 COV 100%

Back-Up Covering Problem



 # CCTV1+2:39 β: 0,2 COV: 71,29% B-COV: 42,78 %



 # CCTV1+2::39 β :0,9 COV:60,84% B-COV:50,38%

Current work and future perspectives

1. Integration of specific technological and normative constraints in the device location for RIS
2. Usage of Optimization Models with respect to Attack Scenarios and required Vulnerability Level

With the support of the *"Prevention, Preparedness and Consequence Management of Terrorism and other Security-related Risks Programme"*
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