Analysis of the hospital claims data from Germany (years 2013 – 2018) and derivation of transfer matrices

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Keywords: healthcare data analysis, overlapping data, transfer probability matrix

Abstract

Antibiotic resistant bacteria are a serious threat to public health system. In order to be able to model the spread of this pathogens within healthcare system network, it is necessary to obtain information on patient movements and the structure of the network. To accomplish that we need informations about patient population and their exchange within the network. In this paper, we analysed hospitalisation records which were provided for the EMerGE-Net project to the Martin Luther University Halle-Wittenberg. We studied and discussed properties of the data with respect to German states. Moreover, we investigated the patterns of patients movements between different states. Then, we took a closer look at resulting hospital network structure, which can be further used to numerically model spread of pathogens.

1 Introduction

Antibiotic bacterial resistance is an increasing problem in healthcare systems all over the world. Strains of resistant bacteria are spreading and they affect our ability to treat other diseases and health problems. They impose increased healthcare costs, longer stay at hospitals and increased mortality. Even though new antibiotics are being developed, they are expected to not be effective against most dangerous antibiotic-resistant bacteria [1]. High rates of resistance against antibiotics frequently used to treat common bacterial infections have been observed world-wide, which indicates that we are running out of effective antibiotics [2]. European Centre for Disease Prevention and Control estimates that more than 670 000 infections occur in the EU/EEA due to bacteria resistant to antibiotics and that number
increases the overall healthcare costs by about 1.1 billion euros. Moreover, approximately 33,000 people die each year in EU/EEA as a direct consequence of these infections [3].

In many studies concerning spread of different types of pathogens, it is essential to derive so-called patients contact networks or network of hospitals which exchange patients (based on e.g. hospital records), cf. [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. In recent studies [16, 17, 18, 14] the focus was on the role of indirect patient exchange between healthcare facilities i.e. when the patient spent at least one day between following admissions at home. In the approach proposed in [16, 17] authors define network consist of the healthcare facilities and society and also derived so-called transfer matrices describing the probability of the transfer of the patient from one to another healthcare facility or from/to society. To do so, it is necessary to estimate several characteristics such as: size of the healthcare facilities, average length of stay of patients in particular facilities and society. In some cases, for re-sampling and up-scaling techniques of data (see [18]) or agent based modelling of pathogen spread in a single hospital (see [19, 20, 21]), detailed information about the patient population structure are required, including sex, age, diagnosis, etc. Thus, to meet these expectations, we conducted an analysis of dataset provided for the EMerGEnET project to the Martin Luther University Halle-Wittenberg. To achieve our goal, we used publicly available code [22] written by us, which detects and classifies transfers from the anonymous hospital stay records.

2 Description of the dataset

The available data consist of 9,415,914 hospitalisation records for 4,101,647 patients collected by the insurance company from January 2013 till end of August 2018. In particular, the database contains the following information: patient anonymized ID, anonymized healthcare facility ID, federal state of healthcare facility, day of the admission, day of discharge, diagnosis (international ICD-10-GM code), patient’s sex and year of birth.

Within dataset we found 9,396,578 complete healthcare facility stay records (i.e. with assigned location and diagnosis codes). There are 1,839 hospital facilities among the whole database located in all regions of Germany (for more details see Table 1). Records without the diagnosis code or region code corresponding to one of the states were omitted from further analysis. States in all tables and images are sorted by their population reported in [23].

3 Data analysis

3.1 Methods

The data was analysed at the server of the Martin Luther University Halle-Wittenberg using secure external access. We used freely available EMERGENERT package developed by Piotrowska & Sakowski, for the documentation, hardware requirements and software see [22].
Table 1: Number of admissions and healthcare facilities depending on the state. States are ordered by their population according to [23].

| State                     | No. of admissions | No. of facilities |
|---------------------------|-------------------|------------------|
| North Rhine-Westphalia    | 2,523,945         | 399              |
| Bavaria                   | 1,165,249         | 343              |
| Baden-Württemberg         | 958,275           | 227              |
| Lower Saxony              | 808,412           | 205              |
| Hesse                     | 779,243           | 151              |
| Rhineland-Palatinate      | 433,619           | 94               |
| Saxony                    | 231,291           | 79               |
| Berlin                    | 743,739           | 54               |
| Schleswig-Holstein        | 373,367           | 74               |
| Brandenburg               | 204,805           | 54               |
| Saxony-Anhalt             | 152,512           | 51               |
| Thuringia                 | 146,843           | 44               |
| Hamburg                   | 489,709           | 37               |
| Mecklenburg-West Pomerania| 173,568           | 41               |
| Saarland                  | 104,963           | 23               |
| Bremen                    | 107,038           | 14               |

3.2 Population structure

Within analysed records we found records for 2,205,843 women and 1,893,988 for men. Maximum number of hospitalizations per patient was between 61 (Saxony) and 214 (North Rhine-Westphalia), except for Baden-Württemberg, where one of the patients had 454 hospitalizations (maximal value) within one state. The average number of hospitalization ranged from 1.9 (Brandenburg) to 2.3 (North Rhine-Westphalia and Thuringia). In all the states, average number of hospitalizations was larger for men than for women, see Table 2. The median of number of admissions per person was equal to 1 independently of sex and location. In Figure 1 we present the structure of patient population in the database.
Figure 1: Structure of patient population.
Table 2: Hospitalizations statistic for given location. States are ordered by their population according to [23].

| State                 | No. of patients in database | No. of hospitalizations per patient | Average no. of hospitalizations per patient | Median of hospitalizations per patient |
|-----------------------|-----------------------------|-----------------------------------|---------------------------------------------|----------------------------------------|
|                       | women | men | min | max | in general | women | men | in general | women | men | in general | women | men | in general | women | men |
| North Rhine-Westphalia| 588 914 | 510 315 | 1 | 214 | 2.3 | 2.2 | 2.4 | 1 | 1 | 1 |
| Bavaria               | 302 142 | 252 417 | 1 | 104 | 2.1 | 2 | 2.2 | 1 | 1 | 1 |
| Baden-Württemberg     | 241 475 | 213 983 | 1 | 454 | 2.1 | 2 | 2.2 | 1 | 1 | 1 |
| Lower Saxony          | 208 065 | 184 622 | 1 | 200 | 2.1 | 2 | 2.1 | 1 | 1 | 1 |
| Hesse                 | 203 685 | 175 437 | 1 | 181 | 2.1 | 2 | 2.1 | 1 | 1 | 1 |
| Rhineland-Palatinate  | 115 049 | 101 514 | 1 | 72 | 2 | 1.9 | 2.1 | 1 | 1 | 1 |
| Saxony                | 52 767 | 54 074 | 1 | 61 | 2.2 | 2 | 2.4 | 1 | 1 | 1 |
| Berlin                | 196 820 | 149 516 | 1 | 88 | 2.1 | 2 | 2.3 | 1 | 1 | 1 |
| Schleswig-Holstein    | 102 692 | 84 452 | 1 | 91 | 2 | 1.9 | 2.1 | 1 | 1 | 1 |
| Brandenburg           | 55 166 | 51 171 | 1 | 169 | 1.9 | 1.8 | 2 | 1 | 1 | 1 |
| Saxony-Anhalt         | 35 750 | 35 184 | 1 | 63 | 2.2 | 2 | 2.3 | 1 | 1 | 1 |
| Thuringia             | 32 059 | 32 609 | 1 | 100 | 2.3 | 2.1 | 2.4 | 1 | 1 | 1 |
| Hamburg               | 137 023 | 109 378 | 1 | 100 | 2 | 1.9 | 2.1 | 1 | 1 | 1 |
| Mecklenburg-West Pomerania | 43 889 | 41 124 | 1 | 94 | 2 | 1.9 | 2.2 | 1 | 1 | 1 |
| Saarland              | 24 070 | 23 026 | 1 | 65 | 2.2 | 2.1 | 2.3 | 1 | 1 | 1 |
| Bremen                | 26 418 | 24 168 | 1 | 96 | 2.1 | 2 | 2.2 | 1 | 1 | 1 |
In Table 3 we present estimated, directly from the dataset, numbers of patients in healthcare facilities and corresponding societies according to each state. It was assumed that patient discharged from a given hospital which is not immediately admitted to another hospital was counted as a member of the society corresponding to the discharging hospital. To classify and count the sizes of the healthcare facilities and corresponding community nodes we used code available here [22]. In addition, we report the average length of stays in healthcare facilities, which varied between 8.2 (Thuringia) and 9.5 (Bremen). The average length of time spent at home between two consecutive admissions for a single person ranged from 243.1 (Bremen) and 293.4 (Hesse), while the average number of patients in healthcare facilities per day was highest in the state with largest population (North Rhine-Westphalia). Both Hamburg and Berlin had large number of patients in hospitals compared to their population.
Table 3: Estimated from dataset number of patients in healthcare facilities and corresponding societies. Average length of stay in healthcare facilities and societies for given location. States are ordered by their population according to [23].

| State                  | Estimated no. of patients in facilities | Estimated no. of patients in societies | Hospital stay mean (standard deviation) [days] | Society stay mean (standard deviation) [days] |
|------------------------|----------------------------------------|---------------------------------------|-----------------------------------------------|---------------------------------------------|
| North Rhine-Westphalia | 10 075                                  | 179 841                               | 8.3 (12.3)                                    | 279.5 (352.2)                               |
| Bavaria                | 4 812                                   | 77 833                                | 8.6 (14.0)                                    | 283.3 (356.8)                               |
| Baden-Württemberg      | 3 864                                   | 61 558                                | 8.4 (13.4)                                    | 274.5 (359.5)                               |
| Lower Saxony           | 3 320                                   | 53 872                                | 8.5 (13.6)                                    | 287.6 (359.8)                               |
| Hesse                  | 3 321                                   | 52 506                                | 8.9 (15.0)                                    | 293.4 (363.5)                               |
| Rhineland-Palatinate   | 1 726                                   | 28 598                                | 8.3 (11.7)                                    | 288.5 (359.8)                               |
| Saxony                 | 957                                     | 15 291                                | 8.6 (13.0)                                    | 271.0 (350.1)                               |
| Berlin                 | 2 986                                   | 48 898                                | 8.4 (13.3)                                    | 275.6 (354.7)                               |
| Schleswig-Holstein     | 1 507                                   | 23 613                                | 8.4 (13.4)                                    | 281.6 (359.1)                               |
| Brandenburg            | 858                                     | 12 250                                | 8.7 (12.9)                                    | 275.1 (358.8)                               |
| Saxony-Anhalt          | 619                                     | 10 314                                | 8.4 (13.0)                                    | 276.2 (354.8)                               |
| Thuringia              | 579                                     | 9 607                                 | 8.2 (12.0)                                    | 254.3 (343.3)                               |
| Hamburg                | 2 066                                   | 31 181                                | 8.8 (13.4)                                    | 284.6 (357.2)                               |
| Mecklenburg-West Pomerania | 708                              | 11 139                                | 8.5 (13.0)                                    | 277.0 (358.9)                               |
| Saarland               | 425                                     | 7 028                                 | 8.5 (12.5)                                    | 272.0 (351.4)                               |
| Bremen                 | 486                                     | 6 123                                 | 9.5 (15.0)                                    | 243.1 (338.1)                               |

In Figure 2 we present the relationship between sizes of healthcare facilities and corresponding communities sizes. For almost all states we distinguished two groups: one consists of small hospitals, which had a relatively small community sizes and second (larger one) where facilities had larger corresponding communities.
(a) North Rhine-Westphalia

(b) Bavaria

(c) Baden-Württemberg

(d) Lower Saxony

(e) Hesse

(f) Rhineland-Palatinate
Figure 2: Dependence of community-node sizes on corresponding healthcare facilities.
3.3 Admissions

Let focus on the characterisation of the healthcare facilities reported in the database. In Figure 3 we see that in all states most of the healthcare facilities had between 1,000 and 9,999 admissions except Hamburg where most of facilities had between 10,000 and 99,999 admissions. Moreover, in all the states hospitals had less than 100,000 admissions apart from Berlin.
Figure 3: Number of healthcare facilities with given number of admissions.
3.4 Number of patients

Further more, if we look at the number of patients admitted to the hospitals (Figure 4) we see that in almost all states most of the healthcare facilities had between 1 000 and 9 999 patients in the dataset. The only exception was Saxony – most of facilities had between 100 and 999 patients within considered time period. In addition, we see that Berlin was the only state with hospitals which admitted more then 100 000 patients.
Figure 4: Number of healthcare facilities with a given number of patients depending on the state.
3.5 Average length of stay

We have investigated duration of reported stays of patients in particular healthcare facilities for all German states. In Figure 5 we present the histograms of the duration of the hospitalisations for all healthcare facilities in given location. Furthermore, in Figure 6 we present the dependence between the duration of the length of stay in society between two admission and a number of such stays in given state. In all the states, the majority of the hospitalizations was under ten days, and most of them were 2 or 3 days long. Number of hospitalizations longer then 30 days corresponds to only 4.58% of all data. Only for one record in dataset the duration of time spend in healthcare facility exceeded 1 000 days. From Figure 6 we deduce that for all the states the structure of the length of stays in society (i.e. between hospitalizations in given state only – interstate records were omitted) was similar. We observe a significant drop of the number of stays in society shorter than 250 days. For longer stays we still see the decrease in number of stays but it is not that fast. Finally in some states, especially ones with highest population (according to [23]), we see another sharp drop after 1 500 days.

(a) North Rhine-Westphalia  
(b) Bavaria  
(c) Baden-Württemberg  
(d) Lower Saxony
Figure 5: Duration of patients stays in healthcare facilities located in considered state.
(a) North Rhine-Westphalia
(b) Bavaria
(c) Baden-Württemberg
(d) Lower Saxony
(e) Hesse
(f) Rhineland-Palatinate
3.6 Patient transfers

For provided dataset, following requirement of modelling framework proposed in e.g. [16, 17], we analysed patient transfers in detail. In general, we distinguished between two types of them: direct transfers between healthcare facilities (without patient stay at home period) and indirect transfer (otherwise). The indirect transfers were further divided into two types: auto-transfer (readmission to the same hospital) and different destination (admission to a different hospital). We detected 5 227 973 patient transfers: 4 774 258 within the same state and 453 715 (8.7% of all transfers) between states. Considerably high number of transfers occurred in Berlin and Hamburg relative to their populations [23].
Table 4: Number of patient transfers for given state. States are ordered by their population according to [23].

| State         | No. of all transfers | Direct transfers | Indirect transfers |
|---------------|----------------------|------------------|--------------------|
|               |                      |                  | all transfers      | auto-transfers     | different destination |
| North Rhine-Westphalia | 1 392 899           | 86 751           | 1 306 148          | 720 498           | 585 650 |
| Bavaria       | 591 704              | 34 905           | 556 799            | 315 343           | 241 456 |
| Baden-Württemberg | 479 669               | 28 488           | 451 181            | 285 102           | 166 079 |
| Lower Saxony  | 393 139              | 24 452           | 368 687            | 225 335           | 143 352 |
| Hesse         | 379 755              | 24 425           | 355 330            | 203 396           | 151 934 |
| Rhineland-Palatinate | 202 829             | 10 127           | 192 702            | 121 787           | 70 915 |
| Saxony        | 119 331              | 5 774            | 113 557            | 71 713            | 41 844 |
| Berlin        | 377 911              | 23 174           | 354 737            | 213 118           | 141 619 |
| Schleswig-Holstein | 174 432             | 10 638           | 163 794            | 107 560           | 56 234 |
| Brandenburg   | 90 150               | 4 820            | 85 330             | 62 198            | 23 132 |
| Saxony-Anhalt | 77 638               | 3 333            | 74 305             | 48 532            | 25 773 |
| Thuringia     | 78 111               | 2 919            | 75 192             | 55 079            | 20 113 |
| Hamburg       | 226 446              | 13 217           | 213 229            | 127 535           | 85 694 |
| Mecklenburg-West Pomerania | 84 136            | 3 516            | 80 620             | 56 993            | 23 627 |
| Saarland      | 55 040               | 3 743            | 51 297             | 29 370            | 21 927 |
| Bremen        | 51 068               | 2 712            | 48 356             | 33 817            | 14 539 |
| Between       | 453 715              | 37 248           | 416 467            | 0                 | 416 467 |
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(g) Saxony

(h) Berlin

(i) Schleswig-Holstein

(j) Brandenburg

(k) Saxony-Anhalt

(l) Thuringia
3.6.1 Transfers between states

Almost all of the transfers between states were indirect (91.8%) (for more details see Table 4, last row). For all the states the percentage of transfers between states was smaller or equal to 20%. The state with the highest percentage of transfers to a different state is Brandenburg (20%) and with the lowest is North Rhine-Westphalia (4%), see Table 5.

To analyse transfers between states more deeply, we checked number of states with records of hospital stays per patient. From Figure 8 we see that most of the patients had records from only one state. Considerable amount of patients had visited healthcare facilities in two or three states and only three patients had records from more then 10 states.

Furthermore we explored the common parts of lists of patients between two given states. From Figure 9 we see that states with biggest populations (according to [23]) had many patients that also visited healthcare facilities in different states. It is also clear that many patients had records from both Hamburg and Schleswig-Holstein, Brandenburg and Berlin, Lower Saxony and North Rhine-Westphalia, Baden-Württemberg and Bavaria while for some states exchange of patients was minor.
Table 5: Percentage of transfers between states (originating in given state and ending in a different one). States are ordered by their population according to [23].

| State                          | Percent |
|-------------------------------|---------|
| North Rhine-Westphalia        | 4%      |
| Bavaria                       | 6%      |
| Baden-Württemberg             | 7%      |
| Lower Saxony                  | 12%     |
| Hesse                         | 10%     |
| Rhineland-Palatinate          | 16%     |
| Saxony                        | 8%      |
| Berlin                        | 8%      |
| Schleswig-Holstein            | 16%     |
| Brandenburg                   | 20%     |
| Saxony-Anhalt                 | 10%     |
| Thuringia                     | 10%     |
| Hamburg                       | 15%     |
| Mecklenburg-West Pomerania    | 10%     |
| Saarland                      | 10%     |
| Bremen                        | 18%     |

Figure 8: Number of patients having record in given number of states.

Next, we analysed in detail indirect transfers between each two states. From Figure [10] we see that even though the numbers of indirect transfers from one state to another and the other way around was not equal, the differences were small. Again the states that had the biggest number of transfers between each other were:
Hamburg and Schleswig-Holstein, Brandenburg and Berlin, Lower Saxony and North Rhine-Westphalia, Baden-Württemberg and Bavaria.

On the other hand, considering only direct transfers, we see that they were not as symmetric as in the case of indirect transfers Figure [11]. There were more transfers from Schleswig-Holstein to Hamburg and from Berlin to Brandenburg than in opposite direction.

Figure 9: Number of patients for which records were found in two considered states.
Figure 10: Number of indirect transfers between two considered states.

Figure 11: Number of direct transfers between two considered states.
3.7 Overlaps

Among all data we found 330,093 overlapping entries. By overlapping records we understand distinct sets of two or more records for a given patient, with non-empty intersection of stay periods, either within the same facility or in other facilities. For the classification of overlaps we followed [24, 25] and used publicly available code [22]. Most of the overlaps were between one or two healthcare facilities. Only 2,611 overlaps were between more than two healthcare facilities (2,577 between three, 34 between four), they correspond to 0.79% of all overlaps and they were excluded from further analysis.

In Table 6 we present results of our analysis of detected overlaps according to their location. We see that states with highest population had highest number of overlaps. The exception were Berlin and Hamburg.

In all the cases most of the overlaps were classified as standard transfer or two entries in a single institution, while usually first type was more abundant. Other types of overlaps were responsible for around 20% of detected overlaps. Except for Berlin and Hamburg, where it was 12.40% and 11.50%, respectively. In Bremen, percent of standard transfer and two entries in single institution was similar. In provided dataset we also found 29,661 overlaps for stays in hospitals located in different states. Considering overlaps for which hospitals were located in different states almost 80% of them were standard transfers.

In fact, for all states, the most common were typical transfers — meaning that both stay periods were covered only by one day and the stays were reported for different institutions — standard, first day and last day transfers, see Figure 12. Moreover, almost none overlaps were longer than a month.
Table 6: Identified types of overlaps for given location. States are ordered by their population according to [23]. Abbreviations for transfers: t. e. s. i. — two entries in a single institution; temp. transfer — temporary transfer; sim. e. s. i. — simultaneous two entries in a single institution; sim. e. t. i. — simultaneous two entries in two institutions; u. t. e. i. — unknown two entries in two institutions; u. m. e. — unknown multiple entries. Abbreviations for states: NRW — North Rhine-Westphalia; BW — Baden-Württemberg; RP — Rhineland-Palatinate; SH — Schleswig-Holstein; ST — Saxony-Anhalt; MV — Mecklenburg-West Pomerania.

| State       | All       | standard transfer | t. e. s. i. | temp. transfer | first day transfer | last day transfer | sim. e. s. i. | sim. e. t. i. | u. t. e. i | u. m. e. |
|-------------|-----------|-------------------|-------------|----------------|-------------------|------------------|--------------|--------------|-----------|---------|
| NRW         | 85 260    | 63.0%             | 16.3%       | 10.1%          | 7.5%              | 0.4%             | 0.1%         | 0.1%         | 2.5%      | 0.1%    |
| Bavaria     | 36 057    | 57.0%             | 20.5%       | 8.7%           | 11.1%             | 0.6%             | 0.1%         | 0.2%         | 1.9%      | 0.1%    |
| BW          | 28 871    | 62.6%             | 17.2%       | 8.8%           | 8.2%              | 0.5%             | 0.1%         | 0.1%         | 2.5%      | 0.1%    |
| Lower Saxony| 25 071    | 62.3%             | 17.2%       | 6.5%           | 11.5%             | 0.7%             | 0.1%         | 0.3%         | 1.4%      | 0.1%    |
| Hesse       | 26 524    | 61.8%             | 21.8%       | 7.5%           | 6.8%              | 0.4%             | 0.1%         | 0.1%         | 1.5%      | 0.1%    |
| RP          | 10 871    | 55.8%             | 22.8%       | 8.2%           | 10.1%             | 0.5%             | 0.1%         | 0.2%         | 2.3%      | 0.1%    |
| Saxony      | 7 022     | 53.6%             | 30.7%       | 7.4%           | 6.2%              | 0.3%             | 0.1%         | 0.1%         | 1.6%      | 0.1%    |
| Berlin      | 27 522    | 61.3%             | 26.3%       | 6.1%           | 4.3%              | 0.4%             | 0.2%         | 0.1%         | 1.3%      | 0.1%    |
| SH          | 11 011    | 61.9%             | 17.8%       | 8.1%           | 9.4%              | 0.4%             | 0.2%         | 0.2%         | 2.0%      | 0.1%    |
| Brandenburg | 5 608     | 57.2%             | 25.3%       | 6.9%           | 9.1%              | 0.4%             | 0.0%         | 0.1%         | 1.0%      | 0.0%    |
| ST          | 3 799     | 59.4%             | 24.2%       | 5.8%           | 8.9%              | 0.4%             | 0.1%         | 0.1%         | 1.1%      | 0.0%    |
| Thuringia   | 3 445     | 56.3%             | 27.6%       | 6.1%           | 7.9%              | 0.4%             | 0.1%         | 0.1%         | 1.5%      | 0.0%    |
| Hamburg     | 14 695    | 66.9%             | 21.6%       | 5.3%           | 4.8%              | 0.4%             | 0.1%         | 0.1%         | 0.9%      | 0.0%    |
| MV          | 4 485     | 52.0%             | 31.9%       | 4.4%           | 10.5%             | 0.3%             | 0.1%         | 0.1%         | 0.7%      | 0.0%    |
| Saarland    | 3 821     | 58.5%             | 19.3%       | 9.6%           | 9.2%              | 0.4%             | 0.1%         | 0.1%         | 2.9%      | 0.1%    |
| Bremen      | 3 759     | 40.7%             | 40.8%       | 6.9%           | 9.0%              | 0.4%             | 0.1%         | 0.3%         | 1.9%      | 0.1%    |
| Between     | 29 661    | 78.8%             | 0.0%        | 9.4%           | 9.5%              | 0.4%             | 0.0%         | 0.1%         | 1.9%      | 0.1%    |
(a) North Rhine-Westphalia
(b) Bavaria
(c) Baden-Württemberg
(d) Lower Saxony
(e) Hesse
(f) Rhineland-Palatinate
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(g) Saxony

(h) Berlin

(i) Schleswig-Holstein

(j) Brandenburg

(k) Saxony-Anhalt

(l) Thuringia
To further analyse overlaps between healthcare facilities from different states we generated a matrix indicating where overlapped transfers started and where ended, see Figure 13. The observed structure of transitions is similar to one showed for indirect transfers between states (cf. Figure 10). There are many transfers from Brandenburg and Berlin, Hamburg and Schleswig-Holstein, Lower Saxony and North Rhine-Westphalia, Baden-Württemberg and Bavaria and another way around.

To deeply characterize the types of overlaps in detail, as in previous reports [24, 25], we used a four-digit classification. The truth is indicated by 1 while 0 means false. First digit indicate if two considered overlaps took place in the same
healthcare facility, second digit: if overlaps have the same diagnoses, third: if two overlaps have the same admission dates and fourth if two overlaps have the same discharge dates. For example code 1100 simply means that two considered overlaps had been reported by the same healthcare facility, in both cases the diagnosis was the same, but there were different dates of admissions and discharges.

The result of such classification is presented in Table 7 with a distinction to states and in Figure 14 without it. We see that in all the states most of the overlaps were classified as 0000 (different: diagnosis, healthcare facilities, admission date, discharge date). They were responsible for 181 654 overlaps out of 327 482. Other two significant types are 0100 and 1000 (respectively: same facility, same diagnose).

It is also worth noticing that the structure of overlaps was similar in all the locations. Four biggest states had the same order of four-digit classification according to the number of overlaps. The rest of the states had slight differences mainly in order of columns 0100, 1000 and columns 0010, 0010.
Table 7: Effect of four-digit classification of the overlapping cases for given location.

| State               | 0000 | 0100 | 1000 | 0010 | 1100 | 0110 | 1010 | 1110 | 0011 | 0111 | 1011 | 0111 | 1111 |
|---------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| North Rhine-Westphalia | 49 186 | 13 740 | 8 254 | 5 682 | 4 856 | 2 077 | 421  | 391  | 205  | 135  | 98   | 45   | 45   | 28   | 7    |
| Bavaria             | 19 341 | 4 611 | 4 365 | 3 198 | 2 565 | 1 156 | 228  | 241  | 132  | 57   | 39   | 32   | 31   | 28   | 17   | 16   |
| Baden-Württemberg   | 16 542 | 4 334 | 2 867 | 2 094 | 1 707 | 716   | 145  | 263  | 63   | 34   | 22   | 24   | 30   | 16   | 11   | 3    |
| Lower Saxony        | 13 644 | 3 740 | 2 321 | 2 318 | 1 641 | 782   | 165  | 206  | 58   | 47   | 50   | 31   | 27   | 16   | 14   | 11   |
| Hesse               | 14 452 | 4 123 | 3 371 | 1 480 | 2 075 | 508   | 109  | 207  | 69   | 35   | 19   | 8    | 32   | 20   | 8    | 8    |
| Rhineland-Palatinate| 5 750 | 1 262 | 1 603 | 970   | 700   | 312   | 64   | 107  | 37   | 18   | 12   | 9    | 10   | 10   | 6    | 1    |
| Saxony              | 3 502 | 830  | 1 270 | 354   | 792   | 140   | 28   | 48   | 22   | 17   | 3    | 1    | 5    | 5    | 1    | 4    |
| Berlin              | 13 663 | 5 129 | 4 136 | 995   | 2 676 | 300   | 96   | 263  | 97   | 55   | 14   | 18   | 25   | 37   | 2    | 16   |
| Schleswig-Holstein  | 5 983 | 1 858 | 1 262 | 902   | 466   | 220   | 48   | 150  | 37   | 23   | 15   | 7    | 17   | 9    | 2    | 12   |
| Brandenburg         | 2 871 | 757  | 961   | 329   | 391   | 200   | 21   | 47   | 9    | 7    | 3    | 5    | 4    | 1    | 2    | 0    |
| Saxony-Anhalt       | 1 927 | 567  | 611   | 249   | 255   | 113   | 15   | 33   | 10   | 4    | 3    | 1    | 5    | 3    | 2    | 1    |
| Thuringia           | 1 682 | 490  | 629   | 229   | 218   | 67    | 16   | 76   | 9    | 7    | 4    | 2    | 12   | 3    | 0    | 1    |
| Hamburg             | 7 825 | 2 860 | 2 242 | 504   | 752   | 245   | 53   | 94   | 47   | 30   | 6    | 19   | 7    | 5    | 2    | 4    |
| Mecklenburg-West Pomerania | 2 093 | 449  | 908   | 359   | 460   | 131   | 13   | 43   | 12   | 6    | 3    | 1    | 2    | 2    | 1    | 2    |
| Saarland            | 2 147 | 486  | 487   | 305   | 192   | 123   | 17   | 42   | 5    | 8    | 0    | 1    | 3    | 1    | 3    | 1    |
| Bremen              | 1 313 | 493  | 940   | 284   | 510   | 108   | 12   | 49   | 21   | 7    | 10   | 3    | 6    | 1    | 1    | 1    |
| Between             | 19 733 | 6 636 | 0    | 2 171 | 0    | 958   | 107  | 0    | 0    | 0    | 24   | 27   | 0    | 0    | 5    | 0    |
Figure 14: A structure of four-digit classification for whole dataset.

Each of four-digit set we analysed further by assigning each diagnose into groups indexed by numbers according to the rules presented in Table 3 in [24] or [26]. In Table 8 we summarised the most frequently appearing diagnosis within the particular types of overlaps for whole dataset. From presented result we see that most often diagnosis for two overlapping entries between different hospitals were diseases of the circulatory system (09, 09). Other frequently present diagnosis were mental disorders (05, 05) and injuries (19, 19). Similarly, the most frequent diagnosis for two overlapping entries with in one healthcare facilities were also mental disorders (05, 05). Other frequent problems were neoplasms (02, 02) and related to pregnancy (15, x).
Table 8: Number of cases for a given diagnosis for particular groups of overlaps. Two record overlaps are included in this table (vast majority among all overlaps).

|      | 0000 | Over. | 0001 | Over. | 0010 | Over. | 0011 | Over. | 0100 | Over. | 0101 | Over. | 0110 | Over. | 0111 | Over. |
|------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|------|-------|
| 05, 05 | 10 512 | 05, 05 | 186 | 05, 05 | 1 614 | 05, 05 | 51 | 19, 19 | 9 808 | 05, 05 | 61 | 19, 19 | 1 124 | 05, 05 | 26 |
| 02, 02 | 9 651 | 05, 05 | 143 | 05, 05 | 1 382 | 05, 05 | 34 | 02, 02 | 5 009 | 05, 05 | 55 | 19, 19 | 664 | 19, 19 | 7 |
| 00, 02 | 9 877 | 05, 18 | 62 | 15, 15 | 1 177 | 05, 18 | 20 | 05, 05 | 4 530 | 02, 02 | 23 | 05, 05 | 376 | 18, 18 | 6 |
| 05, 19 | 6 848 | 02, 02 | 52 | 16, 16 | 1 131 | 09, 18 | 18 | 13, 13 | 2 288 | 15, 15 | 9 | 15, 15 | 372 | 15, 15 | 5 |
| 10, 10 | 5 364 | 05, 09 | 44 | 14, 14 | 846 | 19, 19 | 8 | 11, 11 | 2 044 | 13, 13 | 9 | 14, 14 | 336 | 10, 10 | 5 |
| 13, 13 | 4 525 | 09, 18 | 42 | 05, 19 | 695 | 06, 18 | 7 | 10, 10 | 1 702 | 18, 18 | 8 | 11, 11 | 319 | 13, 13 | 2 |
| 11, 11 | 4 228 | 05, 09 | 44 | 14, 14 | 649 | 09, 19 | 6 | 06, 06 | 1 620 | 14, 14 | 8 | 18, 18 | 198 | 11, 11 | 2 |
| 05, 18 | 3 987 | 05, 06 | 31 | 10, 10 | 494 | 18, 19 | 5 | 14, 14 | 1 527 | 11, 11 | 7 | 06, 06 | 168 | 06, 06 | 2 |
| 09, 19 | 3 631 | 10, 10 | 29 | 09, 19 | 459 | 14, 14 | 5 | 16, 16 | 1 363 | 06, 06 | 7 | 10, 10 | 163 | 02, 02 | 2 |
| 1000 | Over. | 0100 | Over. | 0101 | Over. | 0111 | Over. | 0110 | Over. | 0111 | Over. | 0110 | Over. |
| 05, 05 | 7 433 | 05, 05 | 111 | 05, 05 | 475 | 15, 21 | 62 | 05, 05 | 12 622 | 05, 05 | 167 | 05, 05 | 169 | 19, 19 | 19 |
| 05, 19 | 2 843 | 05, 19 | 57 | 15, 15 | 364 | 14, 21 | 61 | 02, 02 | 5 362 | 02, 02 | 106 | 02, 02 | 30 | 05, 05 | 14 |
| 02, 02 | 2 816 | 05, 09 | 43 | 05, 19 | 339 | 15, 16 | 20 | 09, 09 | 454 | 09, 09 | 48 | 15, 15 | 12 | 15, 15 | 13 |
| 05, 18 | 1 674 | 02, 02 | 43 | 14, 21 | 277 | 05, 19 | 11 | 19, 19 | 401 | 11, 11 | 32 | 09, 09 | 11 | 13, 13 | 12 |
| 05, 09 | 1 505 | 05, 09 | 34 | 05, 18 | 161 | 05, 05 | 9 | 06, 06 | 323 | 19, 19 | 30 | 19, 19 | 7 | 21, 21 | 7 |
| 05, 06 | 1 411 | 15, 21 | 32 | 05, 06 | 67 | 21, 21 | 7 | 13, 13 | 190 | 13, 13 | 21 | 06, 06 | 7 | 02, 02 | 7 |
| 05, 11 | 1 180 | 05, 18 | 32 | 04, 05 | 67 | 15, 15 | 3 | 15, 15 | 157 | 14, 14 | 16 | 13, 13 | 5 | 03, 03 | 3 |
| 01, 02 | 851 | 02, 11 | 20 | 05, 09 | 56 | 05, 18 | 3 | 11, 11 | 128 | 10, 10 | 16 | 14, 14 | 4 | 18, 18 | 2 |
| 04, 05 | 782 | 19, 19 | 19 | 05, 11 | 34 | 02, 21 | 3 | 18, 18 | 122 | 06, 06 | 14 | 12, 12 | 4 | 14, 14 | 2 |
| 05, 10 | 770 | 11, 11 | 16 | 05, 10 | 23 | 17, 21 | 2 | 14, 14 | 88 | 18, 18 | 8 | 11, 11 | 3 | 11, 11 | 2 |
4 Derivation of inter-hospital networks and corresponding transfer matrices

We represented the whole healthcare system as a weighted directed graph, where the nodes represent healthcare facilities and corresponding community-nodes. In the case of direct transfer after the discharge patient goes to another hospital while in the case of indirect transfer to corresponding community-node. Patient from community-node can go either back to the same hospital or to a different one. Thus, in our approach the transfers between community-nodes are impossible. Following [17] and using the code [22], based directly on the provided data (and on length of stay in nodes data in particular), we determined graph edge weights being probabilities of transfer between nodes. Next we used a matrix to code the graph structure, where \((i, j)\) entry is simply the probability of patient transfer from node \(i\) to node \(j\). Clearly, under that definition entry \((i, i)\) would describe the probability of a stay in node \(i\).

During the process of matrix derivation 19 healthcare facilities were omitted due to the fact that the corresponding community-node size was equal to 0. Moreover, we excluded facilities that were inactive for over 90 consecutive days. Thus finally, 1 559 facilities and 1 559 corresponding community-nodes were taken into account. The obtained transfer probability matrix for all states has a clear block structure, c.f. Figure 15. The upper right diagonal block describes probabilities of discharges from healthcare facilities to corresponding community-nodes. The bottom right (diagonal due to the model assumptions) block corresponds to patient exchange between community-nodes. The left upper and bottom blocks represents probabilities of direct transfers between healthcare facilities (direct transfers) and admissions to healthcare facilities from society (indirect transfers), respectively. Transfer matrix has indirect transfer block clearly denser then direct transfer block underling the potential of indirect transfers as a pathogen transmission channel. Although it is not clear from the visualizations, due to matrix size, most of the elements in both direct and indirect blocks are zeros. For direct block only 1.84% elements are not zeroes and for indirect it is 10.22%.

In Figure 16 we present in- and out-degree histograms for the graph. We see that in-degrees were significantly higher then out degrees. That is related to the fact that a hospital patient can be admitted from all other facilities and community-nodes, but can be discharged only to one corresponding community-node or other hospitals. Four hospitals had in-degrees higher than 900, two of them were located in Berlin, one in Baden-Württemberg and one in Hamburg. In Figure 17 we present distribution of out degree for community-nodes. Analysing in-degree is pointless since its always 1.

The diameter of graph for all (not excluded) analysed data was 7 meaning that the distance between every two nodes was not greater then 7. The radius of whole graph was also 7 indicating that there was a node that is not further from any other node than 7. In addition, the density of the graph, understood as a ratio of all edges to \(k(k-1)\) where \(k\) is the number of all nodes, is equal to 0.0305.

If we neglect interstates transfers, the whole graph can be divided into disjoint sub-graphs corresponding to given states, cf. Figure 18. Diameters of state sub-
Figure 15: Visualization of the transfer probability matrix for the whole healthcare network created based on provided data. Healthcare facilities are numbered from 1 to \( n \) and community-nodes numbered from \( n+1 \) to \( n+n, n = 1559 \). (a) probability in matrix with all elements raised to power 0.25 (to emphasize the differences between elements, as they are mostly close to 0), (b) visualization of non-zero elements of matrix. The non-zero patterns of the left half suggest mostly non-zero elements, but this is only due to number of nodes — actually number of non-zero elements is about 10% for indirect transfers block (lower left) and 2% for direct transfers block (upper left).

Figure 16: Histograms of in-degree (a) and out-degree (b) for the healthcare facility nodes.

graphs ranged from 6 (for ones with largest population according \cite{23} to 3 (for ones with smallest population), while the radius vary between states and it was either 4, 3 or 2. The average in-degrees were the same as out-degrees for all considered sub-graphs and they ranged from 77.17 for a state with biggest population to 12.35 for one with smallest one. Graphs for Berlin and Hamburg had relatively high
in- and out-degrees, 32.48 and 24.23 respectively, compared to their populations. The densities of networks were between 0.0959 for Bavaria and 0.494 for Bremen. Information about all sub-graphs is summarized in Table 9.

(a) North Rhine-Westphalia

(b) Bavaria

(c) Baden-Württemberg

(d) Lower Saxony

Figure 17: Histogram of out-degree for the community-nodes.
Figure 18: Visualization of hospital networks (community nodes are omitted) for given state.

5 Summary

For the purpose of modelling the spread of antibiotic resistant bacteria or other infectious diseases, we analysed dataset provided for the EMerGE-Net project to the Martin Luther University Halle-Wittenberg. It allowed us to characterise both patients and healthcare facilities present in dataset. Due to high coverage of the dataset, which consists informations from all German states, we were able to com-
Table 9: Transfer matrix statistics. States are sorted by their population according to [23].

| State                      | No. nodes | No. edges | Avg. in degree | Avg. out degree | Density          | Diameter | Radius |
|----------------------------|-----------|-----------|----------------|-----------------|------------------|----------|--------|
| Whole                      | 3 118     | 2.96 · 10^5 | 94.98         | 94.98          | 3.05 · 10^{-2}  | 7        | 4      |
| North Rhine-Westphalia     | 654       | 50,469    | 77.17          | 77.17           | 1.18 · 10^{-1}  | 6        | 4      |
| Bavaria                    | 554       | 29,395    | 53.06          | 53.06           | 9.59 · 10^{-2}  | 6        | 4      |
| Baden-Württemberg          | 362       | 15,019    | 41.49          | 41.49           | 1.15 · 10^{-1}  | 6        | 4      |
| Lower Saxony               | 322       | 10,622    | 32.99          | 32.99           | 1.03 · 10^{-1}  | 6        | 4      |
| Hesse                      | 244       | 10,046    | 41.17          | 41.17           | 1.69 · 10^{-1}  | 6        | 3      |
| Rhineland-Palatinate       | 154       | 3,978     | 25.83          | 25.83           | 1.69 · 10^{-1}  | 6        | 4      |
| Saxony                     | 144       | 3,430     | 23.82          | 23.82           | 1.67 · 10^{-1}  | 5        | 3      |
| Berlin                     | 92        | 2,988     | 32.48          | 32.48           | 3.57 · 10^{-1}  | 4        | 2      |
| Schleswig-Holstein         | 120       | 2,842     | 23.68          | 23.68           | 1.99 · 10^{-1}  | 5        | 3      |
| Brandenburg                | 102       | 2,065     | 20.25          | 20.25           | 2 · 10^{-1}     | 4        | 3      |
| Saxony-Anhalt              | 96        | 1,874     | 19.52          | 19.52           | 2.05 · 10^{-1}  | 5        | 4      |
| Thuringia                  | 82        | 1,450     | 17.68          | 17.68           | 2.18 · 10^{-1}  | 5        | 3      |
| Hamburg                    | 60        | 1,454     | 24.23          | 24.23           | 4.11 · 10^{-1}  | 4        | 2      |
| Mecklenburg-West Pomerania | 68        | 1,184     | 17.41          | 17.41           | 2.6 · 10^{-1}   | 4        | 3      |
| Saarland                   | 38        | 656       | 17.26          | 17.26           | 4.67 · 10^{-1}  | 3        | 2      |
| Bremen                     | 26        | 321       | 12.35          | 12.35           | 4.94 · 10^{-1}  | 3        | 2      |

We discovered that most of them behave according to their populations, i.e. number of healthcare facilities, patients, transfers and overlaps is proportional to the size of population reported in [23]. The only exceptions are Berlin and Hamburg. That is reasonable due to nature of those states: these are large metropolitan areas. They have higher number of healthcare facilities, patients, transfers and overlaps than states with similar population size.

From the dataset we were able to extract information about patients transfers. We characterised both transfers taking place within the same state and between states. Closer look into interstate transfer allowed us to indicate the states with the highest exchange of patients. Moreover, to better understand the movement of the patients in the network we analysed overlaps appearing in the records. In all the states around 80% of them were classified as standard transfer or two entries in
single institution, except for Berlin and Hamburg were it was almost 90%.

Our analysis allowed us to build transfer network for whole country as well as for individual states separately. The results indicate that for states with higher population the network has higher density and radius. Derived transfer matrices can be used further to model the spread of pathogen in details like e.g. in [16] or [17].

Acknowledgements

This work was supported by grant no. 2016/22/Z/ST1/00690 “Effectiveness of infection control strategies against intra- and inter-hospital transmission of Multidrug-resistant Enterobacteriaceae — insights from a multi-level mathematical NeTwork model” of the National Science Centre, Poland within the 3rd JPI ARM framework (Joint Programming Initiative on Antimicrobial Resistance) co-funded grant no 681055 for the consortium EMeRGE-Net (Effectiveness of infection control strategies against intra- and inter-hospital transmission of Multidrug-resistant Enterobacteriaceae). We thank the EMeRGE-Net team at the Martin Luther University Halle-Wittenberg for providing access to the insurance data on their server in joint analyses.

Supplementary materials

S1: Numerical data for probability transfer matrix.

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