For office use only

T1 ________

T2 ________

T3 ________

T4 ________

Team Control Number

2018043

2018

For office use only

F1 ________

F2 ________

F3 ________

F4 ________

The International Mathematical Modeling Challenge (IM^2C) Summary Sheet

We live in the world full of diverse options. We are lucky to have many possibilities to choose from. But we should know how to make a good decision. The most logical thing would be to **set criteria** and to make comparisons based on them.

Before the decision is made, we should remember which criterion is the prior one. In terms of the quality and the success rate of any hospital the most important point is the ratio of evitable deaths (declared variable *e)* to the total number of mortal cases (*h*).

There are many factors that indicate whether there was a possibility to avoid patient's death: correct diagnosis, hospital-acquired infections, failure of a human factor, patient's age (*a*), the mortality (*m*) by his/her diagnosis and its stadium (*g*), urgency of admission (*u*), comorbid illnesses (*c*) and their influence on the treatment.

In case of death caused by misdiagnosis, a nosocomial infection or failure of a human factor, the death can be automatically considered evitable.

With another factors it is not so clear, so we developed a 5-point scale to be able to measure them equally. Each factor influences the death to different extent. Mathematically it means the variables have different coefficients: *3a, 3m, 2g, 1c, 1u.*

Each case will be **considered separately**. Either we directly decide whether it was an evitable mortal case, or we pass it to the 2nd step in which patient's case gains some points while considering the factors with the indirect influence on death. After that, thanks to a stated limit, we will be able to decide whether it was evitable or it was not. Logically, the hospital with lowest ratio of evitable deaths to the total number (*e:h)* is the best one.

To the top *x* results of the previous model we can add other criteria for an objective comparison. Qualification and the number of staff (*s*), medical machines (*f*), its total variety, average age, outdoor and indoor environment (*n*) and investments (*b*) play an important role as well. With the same intention as before, we assigned them coefficients to point out their importance: *2s, 2f, 1n, 1b.* We developed a system of comparisons: At first according to the individual criteria, for which they get points based on their placing. Finally, after counting up all points gained, after comparing them and after **ordering** them **in descending order** we can form the ranking of the best hospitals.

We can imagine a program which might automatically in a few seconds choose the best hospital thanks to this algorithm.

User-friendly memo

How do you choose the best hospital if you have all information about each and you are willing to travel for your healthcare with an objective to find the highest quality? This model can help you to pick the best hospital. The only thing you need to do is to follow these instructions.

To measure the quality of a hospital it is necessary to assess the proportion of evitable deaths and the total number of deaths in a hospital for the last, let us say, 5 years. The intention of the following calculation is to confirm the death was unavoidable. **We consider each mortal case separately.**

The first thing that should be considered is the correctness of diagnose, the hospital-acquired infections and the failure of human factor. If the inpatient died because of one of these factors, the death was evitable and the hospital failed.

If the death was caused by other factors, the (non)avoidance of death will be considered in following steps:
At first, choose gender and the age-group of the patient. See the table and find the proper number of points. Then multiply obtained points by coefficient assign, which is in this case 3. It symbolizes the influence of this factor on patient's death.
The next step is the next line of the table. Add the percentage of mortality multiplied by 5 and then by 3. Then add the next line, the gravity multiplied by 2 and at the end adding up the points obtained of the two last factors, the comorbidity and urgency of admission.

			Points				
Factor	**Coefficient**		**1**	**2**	**3**	**4**	**5**
Age (a)	*3*	*man*	x	[1;34]	[0;1] or [35;54]	[55;79]	80+
		woman	[5;14]	[1;4] or [15;39]	[0;1] or [40;64]	[65;84]	85+
Mortality (m)	*3*		Percentage of mortality by the diagnosis multiplied by 5				
Gravity (g)	*2*		initial	x	advanced	x	critical
Comorbidity (c)	*1*		none	x	1	x	1+
Urgency (u)	*1*		not assigned	x	elective/ scheduled	x	emergency/ urgent

The equation will be following:

$$3a + 3m + 2g + c + u < 21 \Rightarrow \textit{evitable death}$$

The translation of the equation is: If the result is lower than 21, the death was evitable. Contrarily, if it is higher than 21 then the death was inevitable and it was not the fault of the hospital.
Now just count up the number of evitable deaths you obtained and divide it by the total number of deaths during the last *x* years. The lower is the result, the better quality has the hospital. That is sufficient to make the 1st ranking.

To make the results more objective, top *x* hospitals according to the 1st ranking will be examined and compared regarding their staff (*s*), facilities (*f*), environment (*n*) and the budget (*b*). Hospitals will be ordered in descending order by the following factors. Just put the information in the equations and calculate each fraction (it means divide the numbers put in the equations).

$s_1 = \frac{\text{sum of physicians' credits}}{\text{total no. of physicians}}$

$s_2 = \frac{\text{the total no. of medical staff}}{\text{the capacity of the hospital}}$

$f_1 = \frac{\text{no.of med.machines available}}{\text{the capacity}}$

$f_3 = \text{total no. of types of machines}$

$o = \frac{\text{relaxation zones}}{\text{plot of land}}$

$i = \frac{\text{sum of wards' area}}{\text{the capacity}}$

$p = \frac{\text{total number of free parking places}}{\text{capacity of the hospital}}$

$b = \frac{\text{investments}}{\text{budget size}}$

And then, the hospitals will be ordered in ascending order by following factor:

$$f_2 = \frac{\text{sum of age of all machines}}{\text{the no.of machines}}$$

For each factor, the hospital gains a certain number of points depending on its position. If the number of chosen hospitals desired to compare is 5 then:
1st place = *x* points, 2nd place = 4 points, 3rd place = 3 points, 4th place = 2 points, 5th place = 1 point.

Then imply count up:
s= *points gained for* s_1 + *points gained for* s_2
f= *points gained for* f_1+ *points gained for* f_2+ *points gained for* f_3
n= *points gained for n*
b= *points gained for b*

The final value of points for each hospital will be calculated thanks to following formula:

$$2*s + 2*f + n + b$$

To get the final order of hospital, the hospitals need to be ordered in descending order according to their final points calculated before. The hospital on 1st place is the best one.

If only we were healthy for the whole life! Every one of us wishes that, do not we?

Let us turn back to reality. If we end up seeking a professional health care and we want to choose the best hospital, but we do not know which one it is, in this case, as we are mathematicians, we can apply the following mathematical models full of variables to be sure we make the best possible choice.

We created two models as an answer to the question of how to evaluate hospitals objectively. The first model is based on the rate of mortal cases which might have been prevented. The second one is enriched by others criteria.

The first model: An evitable death

To decide which death was evitable and which was not, is quite an awkward matter and it is not always evident. Having said (written) that, we designed a number of conditions with the intention to be as much objective as possible.

We decided to divide the factors in two groups:

a. having direct impact on the death:
   - whether the patient was **correctly diagnosed**
   - **nosocomial infections**
   - **human failure**, such as a transplantation of wrong blood type, a fault committed during an operation,…
b. having indirect impact on the death:
   - **mortality by the specific diagnosis**
   - **age** and **gender**
   - **gravity** of the health state at the moment of patient's admission
   - **urgency of admission**
   - **comorbidity**

Factors having direct impact on the death

Knowing the exact number of deaths and theirs circumstances (for example) for the last 5 years, we can use this data to count how many deaths could be avoided.

As we have already mentioned above, there are a few factors showing us directly the death was evitable. With the following steps (every factor considered is a step) we find out the total number of evitable deaths represented with variable e (evitable).

Correct diagnosis

To diagnose a patient correctly is the key to success. However, it is not always unequivocal because many of illnesses have the same or very similar symptoms. According to a Czech scientific source[1], the **misdiagnosis** presents a **40% of medical faults** in general. When a patient dies from a misdiagnosis, or a wrong medical treatment as a consequence of a misdiagnosis, the hospital is at fault and no other polemic is needed.

[1] 04/04/2018 [*https://www.linkos.cz/lekar-a-multidisciplinarni-tym/kongresy/po-kongresu/databaze-tuzemskych-onkologickych-konferencnich-abstrakt/chyby-a-omyly-v-onkologii-a-jejich-management/]*

Calculating with an incorrect diagnosis

Every case of death is going to be considered separately and it will pass through all factors. If it is proved, that the cause of death was the misdiagnosis (or its consequences), we regard the death an evitable case and we will not continue judging it. If so, we increase the value of the variable *e* by 1.

Nosocomial infections

During the stay in the hospital there is a danger of **hospital-acquired infections**, also known as nosocomial infections. The longer is the stay in the ward, the higher is the danger of contagion. We observe constant rise in cases with nosocomial infection, because of the constant increase of the number of microbial strains resisting any treatment.

The infection can originate from poor hygiene, another infected patient, infected staff, or other undetermined source. If a patient dies from consequences of the unsatisfactory environment in the hospital (and not from the main diagnosis), the hospital is clearly at fault.

Calculating with nosocomial infections

Having mentioned this factor has a direct impact on death, if this becomes a ground of the death, the value of the variable *e* increases by 1, as in the previous step.

Human failure

Medical accidents can be understood as a failure of medical procedure or an **error of hospital staff** during the provision of care. The human errors are associated with inexperienced physicians and nurses, new procedures, extremes of age, complex or urgent care etc. The most common causes of human failure are connected with the cognitive errors (as overvaluing the first data, which may color judgment), sleep deprivation, time pressures, and others.

These errors can include already mentioned misdiagnosis (which causes comorbidity and later, death), administering wrong medications, swapping individual medical treatments of in-patients, giving wrong blood type, etc.

If the human failure is proved, standards and regulations for medical malpractice vary by country and jurisdiction within countries.

Calculating with human failure

We apply the same method, as in both previous; that is by proving this kind of failure, variable *e* increases by 1.

Factors having indirect impact on the death

There are other factors; they can under certain conditions lead to death. The hospital usually cannot influence them, although there are some exceptions, as for example urgency of admission.

With a mathematical correlation between the different coefficients we are able to decide, whether it is justifiable to blame the hospital. That means it is necessary to consider all the factors of this category. In this mathematical model we will proceed as follow:

1. To every factor we assign a variable
2. To each variable we assign a coefficient according to the importance of the factor
3. We calculate the value of each variable using 5-point scale
4. We count up a total value gained for each case
5. We establish a limit as a border between an evitable and inevitable death
6. Knowing the exact number of evitable deaths we can determine the proportion of evitable deaths within the total number of deaths in the hospital

Based on this proportion we can compare different hospitals.

Mortality by the diagnosis

There are accessible **databases showing mortality** by various diagnoses. This factor influences the death to a large extent, bearing in mind there are still some **incurable diseases**. By AIDS, Fatal familial insomnia, "Brainerd" diarrhea and others, the death of a patient is for sure inevitable.

Calculating with mortality by the diagnosis

In following calculations the mortality by the diagnosis of the patient will be represented by *m* (mortality).

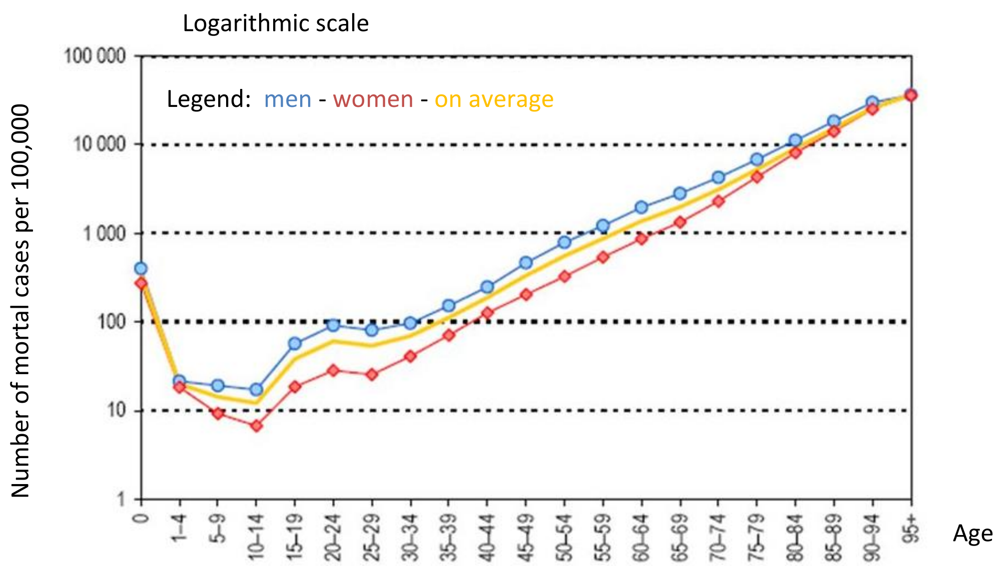
The value of the variable *m* is the probability (expressed by a number of interval [0; 1]) of death for definite diagnosis, multiplied by number 5.

$$\boldsymbol{m = 5 * probability\ of\ death};\ m \in [0; 5]$$

The number 5 multiplies the probability, because we need to have the same scale for valuation of each factor. In the next steps we are going to use the 5-point scale and that led us to the multiplication of the probability bearing in mind it belongs to the interval <0; 1>. With this move we modify the interval of m, which now is <0; 5> and the variable *m* is equal to all other variables.

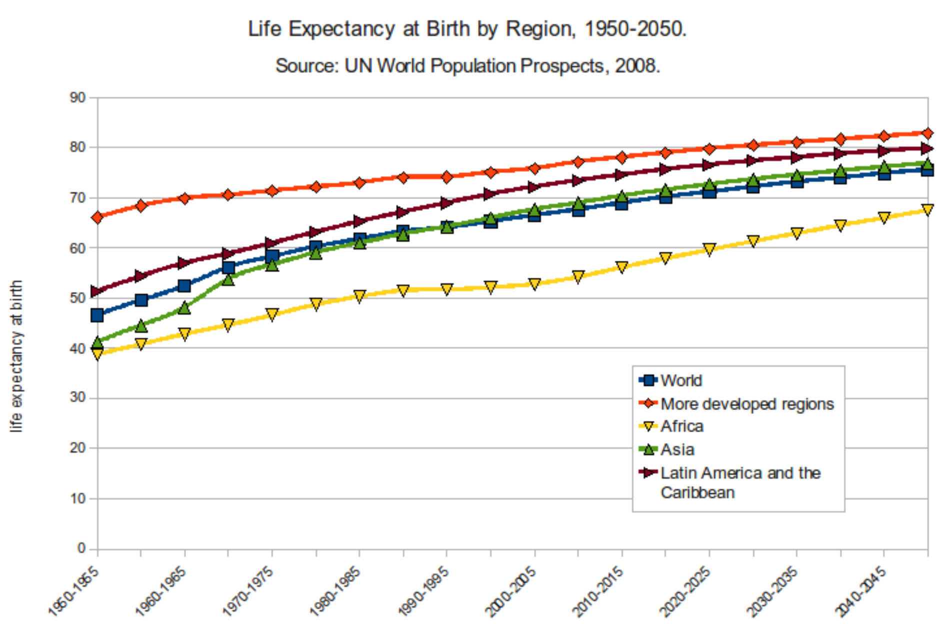
Age and gender

Nobody can deny there is a correlation between age and mortality. Usually is thought the higher age, the higher mortality. But it is not correct, because **the dependence is not lineal**, as we can see in the graphic:



1: **Graphic showing average mortality in developed countries**

From the graphic is also clear, there is an age difference between men and women. In general for **men** the **mortality** is **higher** than for women. But we have to emphasize, the particular difference between age and gender varies from continent to continent. We suppose, this model will be applied in developed countries. Therefore we can use an average of these.



2: **Graphics showing life expectancy in different continents**

Calculating with age and gender

Having written, we are going to use a 5-point scale to evaluate every factor, we decided to divide the curve of mortality of the graphic nº 1 in 5 parts, but still differently for men and women. We got 5 age-intervals for each gender, summarized in the following table:

	Gender:	Points:	1	2	3	4	5
a=	male		-	[1; 34]	[0; 1] ∪ [35; 54]	[55; 79]	80+
	female		[5; 14]	[1; 4] ∪ [15; 39]	[0; 14] ∪ [0; 64]	[65; 84]	85+

These intervals are based on the number of mortal cases per 100,000 inhabitants, i. e. the axis *y*. We observe in the graphic, the blue curve is always higher than 10 deaths per 100,000 inhabitants. That is the reason why in any case a man cannot score just 1 point.

We will represent the points scored by variable *a* (age), in other words the value of *a* will be assigned according to the created table.

Stadium

Chances to be cured are substantially higher when the disease is discovered in the initial stage. Then the curing/healing process is more effective and usually also shorter. In other words, curing opportunity depends on gravity of the health state at the moment of patient's admission. When a disease is discovered/cured since the critical stadium the patient can be found in danger of life, because the **time plays an important role**.

Calculating with the stadium

In this model patient's stadium will be represented by variable *g* (gravity). Its value will be assigned according to the following table:

g=	Points:	1	3	5
	Stadium:	initial	advanced	critical

Urgency of admission

The urgency of admission can be divided in 3 types: **emergency, elective** and **not assigned**.

Emergency admission occurs within 24 hours. Such a patient would be for example at risk of serious morbidity or mortality and requiring urgent assessment or resuscitation, suffering from a drug/alcohol overdose, experiencing severe psychiatric disturbance and in all other cases whereby the health of the patient or other people is at immediate risk.

Elective admission occurs after more than 24 hours. A patient is often supposed to have an admission scheduled in advance.

Not assigned admission is for example admissions for normal delivery (obstetric) or admissions which begin with the birth of patient or planned readmissions[2] etc.

[2] *[http://meteor.aihw.gov.au/content/index.phtml/itemId/269986]* 05/04/2018

An **urgency** status can be assigned for admissions of the types listed above in case the patient who is to have an obstetric admission may be admitted on an emergency basis.

Calculating with the admission

This factor will be represented by variable *u* (urgency). Its value will be assigned according to the type of admission we have listed above. To calculate the value of the variable *u* we will use the following table:

$u=$	Points:	1	3	5
	Admission:	not assigned	elective/scheduled	emergency/urgency

Comorbidity

The term *comorbidity* means presence of one or more **illnesses side by side** the existence of the main diagnosis and at the same time it means the **influence** it has on the main diagnosis or **its treatment**.

The comorbid illness may come before, coexist or come after discovery of the main diagnosis. Correlation of two or more comorbid illnesses which has the same patient may be relatively independent or causally dependent which means one illness is conditioned by appearance of another.

Calculating with comorbidity

In this model we will take into account just the number of comorbid illnesses with a direct impact on patient's treatment, because just these ones could have an impact on patient's death. Points scored by examining this factor will be represented by variable *c* (comorbidity).

$c=$	Points:	1	3	5
	No. of comorbid illnesses	none	1	1+

Mathematical description of the first model

In this section we are going to describe our model purely mathematically. We can say, it is possible to divide it in two parts: in 1st one we directly count up the number of evitable deaths, but in 2nd one we have to consider each mortal case in detail. The intention is to find out the proportion between evitable (declared *e*) of all mortal cases (declared *h*).

Calculating with factors having indirect impact on the death

We have already declared and in detail described all variables we are going to use in this model. Now we assign a coefficient to each variable by its importance. Age and gender, together with the mortality by the diagnosis have the biggest impact on death so we choose the coefficient 3. Gravity of the health state at the moment of patient's admission is also an important factor, but not that much as the previous two, so the coefficient will be 2. Then urgency of admission and comorbidity do not influence the death to the same extent as other factors, so their coefficient is 1. Then we multiplied every variable by the value of its **coefficient: *3m, 3a, 2g, u, c.***

Thanks to these calculations we found out the minimum number of points for factors having indirect impact on the death, which is 7, and the maximum, which is 50. We are going to calculate the number of points for every mortal case in the hospital. The higher value we get the more limited options the hospital had to save the patient. The participation of the hospital on the death and points scored are directly proportional.

Now, we need to find the limit defining whether the death was evitable or not. First of all, we will examine the factors with coefficient 3, which are the most important. If one of these factors (mortality by the diagnosis or age and gender) has the largest possible value (3*5=15) and the other factors have the lowest possible values, the number of points for this case will be 19.

However, maximization of only one factor is not sufficient to call the death inevitable (example: we cannot call the death of a healthy 81- year old man inevitable) and so we have to increase the value of at least one other factor by one degree (in our system of calculations, the smallest possible increase is by 2 points in case of comorbidity or admission). So the border between evitable and inevitable death is 21 points. Every case with total value lower than 21 points will be considered an evitable death, if so, we increase the value of variable *e* by 1.

$$(3 * m) + (3 * a) + (2 * g) + (u + c) < 21 \Rightarrow e = e + 1$$

Knowing the total number of evitable deaths *e*, we can express the ratio between evitable deaths and total number of deaths *h* and compare different hospitals. The hospital with the **lowest ratio is the best** and the most reliable hospital according to the mortality.

$$ratio = \frac{e}{h}$$

Giving an example

In this section we move from the theoretical level to real examples, which will serve us as a verification of our mathematical model. In other words they will show us, whether the model works and how it works.

Below we present the specific data for four examples together with the calculations of values of declared variables, which are representing the factors participating in this model. It is important to say that every example is a deceased patient. Afterwards we are going to think about, whether it was possible to avoid this death or not.

Data and calculations for 1st example:
The first example is a 35-year old man, with diagnosed severe acute respiratory syndrome in initial stage with no comorbidity. Urgency of his admission was emergent – within 24 hours but the patient died of a nosocomial infection.
In this case, we can automatically consider the death evitable as the cause of his death was a hospital-acquired infection.

Data and calculations for 2nd example:
The second example is a 75-year old woman, with diagnosed breast cancer in advanced stage, but no comorbidity. Urgency of her admission was elective – within 24 hours. The calculation in this case will be following:

$a = 4*3=12$ *points*

$m = (0.16*5)*3= 2.4$ *points*

$g = 3*2 = 6$ *points*

$u = 3$ *points*

$c = 1$

Total score: 24.4
The total score is higher than the stated limit, which implies that this death we will not consider evitable.
By elderly people suffering from cancer, and what is more in advanced stage, chances to survive are not high and logically we cannot blame the hospital.

Data for the 3rd example:
The third example is a 20-year old woman, with diagnosed Ebola virus in initial stage with no comorbidity. As the woman is having diagnosed Ebola, the urgency of admission is emergent. The calculation in this case will be following:

*a = 2*3 = 6 points*
*m= (0.7*5)*3 = 10.5 points*
*g= 1*2 = 2 points*
u= 5 points
c=1 points

Total score: 24.5
The total score is higher than the stated limit, which implies that this death we will not consider evitable.
Although the woman was young mortality by this diagnosis is really high and the hospital did everything right, so the death was inevitable.

Data for the 4th example:
The fourth example is a 33-year old man, with diagnosed melanoma skin cancer in an advanced stage with one comorbidity. His urgency of admission is not assigned. The calculation in this case will be following:

*a = 2*3 = 6 points*
*m= (0.16*5)*3 = 2.4 points*
*g= 3*2 = 6 points*
u= 1 points
c=3 points

Total score: 18.4
The total score is lower than the stated limit, which implies that this death we will consider evitable.
In this case, the fault was with a high probability on the side of the hospital as the mortality by the diagnosis is not so high and the patient was relatively young. Procedures of hospital staff failed somewhere.

The second model: The best hospital

To pick the best hospital various criteria should be considered, because every hospital has its pros and cons. This second model of evaluation consists of a complex comparison according to following factors:

- **staff**
- **facilities**
- indoor and outdoor **environment**
- budget
- **references** of hospital's own in-patients

This model can be applied to top 10 or top 5 hospitals of the first model of this solution. The variable *x* will represent the number of hospitals chosen by the user of this model.

Staff

To determine who is the best physician or the best nurse. For someone it is the one with more **experience** or better **studies**, for example at more renowned university according to the world rankings[3], for another one it may be the one having nicer **attitude to the patients**. The most suitable would be to combine all these characteristics.

A physician should never stop studying and that is also established by law. An international system called "*Continuing Medical Education"* (further only *CME*), was created with an intention to give further information to all physicians in the world about new or developing fields of their domain.

In this system physicians need to gain a minimal number of credits set per 5-year cycle. These credits are gained by praxis, specialized studies, active or passive participation in medical educational activities (lecturer/audience), scientific publications, etc. Based on the **accreditation** we are able to evaluate physicians objectively.
CME system is common for most of developed countries (Canada, Japan, UK, etc.) and the accreditation of all physicians is elaborated in an on-line database. However there are still some countries having an own system. In this case it would be possible to calculate the accreditation on our own, knowing in detail the whole medical staff (without charwomen, servicemen, etc.) of assessing hospitals. This system is current in many countries, so we are going to use the data of already existing databases.

That was on one hand. And on the other, there is also another important point we need to mention: the **number of employees per patients**, or rather the capacity of the hospital. There are countries/cities suffering from lack of medical staff. So we need to consider also this factor by measuring the quality of the hospital, because there is a correlation between the attitude to

[3] *[https://www.topuniversities.com/university-rankings/university-subject-rankings/2018/medicine]* 06/04/2018

patients and the length of shift of the staff, as well as between the length of shift and the number of staff in the ward/hospital.

Calculating with staff

Staff is going to be represented by variable *s* (staff). Having mentioned we should consider not only experience of employees but also their total number, we differentiate: s_1 will represent the accreditation according to the *CME* system and s_2 will represent the proportion of medical employees to the capacity.

The intention of s_1 is to show the average experience together with the knowledge of all physicians of the hospital. We know that the average accreditation is the sum of *CME* credits of all physicians divided by the total number of physicians.

$$s_1 = \frac{\sum physicians' credits}{total\ no.\ of\ physicians}$$

Afterwards we calculate the proportion of staff per the number of patients, because we do not need only qualified and skilled staff, but also have enough shift workers.

$$s_2 = \frac{the\ total\ no.\ of\ medical\ staff}{the\ capacity\ of\ the\ hospital}$$

Facilities

The medical examination does not depend only on experience of physicians but also on available facilities. We can divide the hospital facilities in categories: supplies, machines, furnishings and further equipment.

We suppose departments are properly furbished and with all supplies needed. Without them a sterile examination would be impossible. Therefore we will take into account just the **type, age** and the **total number of machines** (EKG, oximeters, ultrasound machines, echocardiograph, bone densitometers, etc.).

Science and technologies continue advancing together. And they need to be modernized in hospitals. Only then patients can get an efficient treatment, get test-results more quickly or undergo surgery performed in shorter time, or more safely than it was possible before.

Calculating with facilities

Having written important is not only the number of working machines, we decided to differentiate: variable f_1 expresses workload of machines, f_2 expresses their average age and, finally, f_3 expresses how many types are available in the hospital.

A hospital with a bigger capacity, is supposed to have more medical machines to not prolong the waiting period, which also decide on patients' satisfaction. Therefore we calculate the proportion of machines per patients:

$$f_1 = \frac{no.of\ med.machines\ available}{the\ capacity}$$

We were talking also about the modernization and upgrades of the technologies. To find out which hospital has the most current types of the medical machines. We calculate it simply; how many years they have on average.

$$f_2 = \frac{\sum age\ of\ all\ machines}{the\ no.of\ machines}$$

To describe the variety of medical machines in a hospital, we compare the picked hospitals on the basis on how many types of those machines they have available (we remind, we take into account only working machines). The variable f_3 expresses then the total number of them per hospital.

$$f_3 = total\ no.\ of\ types\ of\ machines$$

Environment

The environment in which you spend your time has an influence on your personality as well as on your health. We represent it with variable *n* (environment). However the environment is a complex criterion, so we divided it in three sub-criteria.

Outdoor environment

We should consider the outdoor environment and the **areal of the hospital** as the next criterion. Of course, this factor has a considerable importance for a patient just in case we know in advance a longer hospitalization will be needed and the state of health of the in-patient will allow more than staying in the ward.

An example: If there were someone with two-week (or even longer) stay, and on top of that if it were during summer months, a well-tended park would be a big advantage of the hospital. Taking a walk as a light physical activity, enjoying the sunlight as a natural source of vitamin D can substantially improve your mental health. In addition, for visitors it presents a more pleasing place to see an in-patient. Subsequently, your piece of mind has also certain influence on the length of your recovery.

In this point we will count with all kinds of zones, which provide certain "mental recreation". Let us call them relaxation zones. However we designed a number of conditions when this zone can be considered a relaxation zone. The place should:

- be an **outdoor zone**
- provide safe barrier-free, primarily wheelchair accessible, **walking paths** where cars neither ambulances do not run
- provide **places to sit**, such as benches, seats,…
- provide **shade places** brought by trees, shelter roofs,…
- have an access to **drinking water**, which can be ensured by a drinking fountains, buffet…
- in spite of everything, it should be **at least of its 25% a green** zone, that means trees, flowers, any plants or at least a lawn is required, above all it is about bringing natural environment to the hospitalized

The requirements are high and the conditions are strict. If it does not meet them all, it is sincerely irrelevant to consider it a real plus of the hospital.

Calculating with environment

The coefficient expressing extent of the influence of the environment is in our model represented by variable *p* (park).
We calculate its value area of relaxation zones in relation to the total area of the plot of land of the hospital. Both expressed in m^2.

$$o = \frac{relaxation\ zones}{plot\ of\ land}$$

Logically, the value of *p* will never reach the value of 1, because it would mean, that the plot is for 100% any relaxation zone, but in fact there are other facilities such as hospital buildings, parking place, etc.

Parking

The number of **disposable parking places** may influence the satisfaction of the patients. Therefore we decided to consider it as another criterion. The capacity of parking places should be adequate to the capacity of the hospital.

In this model we will take into account only those parking places which are **free**. Then it is a real advantage of the hospital.

Calculating with parking places

Mathematically the proportion between parking places and the capacity of the hospital we write down as a simple fraction. It will be our next variable, variable *p* (parking).

$$p = \frac{total\ number\ of\ free\ parking\ places}{capacity\ of\ the\ hospital}$$

After quantification of the value of *p* we order our *x* hospitals chosen and assign them the relevant number of points for this criterion.

Indoor environment

Not only the outdoor areal is important, but also the inner space where the patient spends most of his time. He/she is supposed to have enough space for his/her own personal use (toilet articles, etc.). A hospital is supposed to ensure sanitary facilities for each in-patient, so the only thing we will consider is how much space of ward gets a patient in the average.

Calculating with indoor environment

Then the calculation is not complicated: a simple fraction, named variable *i* (indoor) stating an inverse proportion between the total area of all wards in m^2 and the capacity of the hospital.

$$i = \frac{\sum ward's\ area}{the\ capacity}$$

Budget

In the long run there is another factor having impact on the evolution and the quality of hospitals: it is how they manage their own budget.
If they do not save enough money, or more precisely if they run in debts, they cannot afford the newest technology, they cannot invest in upgrading the facilities, the state of hospital buildings, etc.

It is not only about the budget size, but also about the stability achieved by good management of the disposable budget. Some part of it goes to wages and salaries of the employees, another part goes to power bills or to paying off debts (if there are some), etc., but there should be a part going to new investments. These should manifest itself (as it is supposed) especially in **modernization** of departments such as wards and the healthcare in general. That is the part of budget we are interested in.

Calculating with budget

The hospitals do not have the same budget size, so, logically; we cannot compare them on the basis of it. More reasonable is to calculate the percentage of the budget spent on further investments. The percentage will be represented with variable *b (*b̲udget).

$$b = \frac{investments}{budget\ size}$$

Mathematical description of the extended model

The user of our model has the possibility to choose the first *x* hospitals ordered according to the lowest mortality (see the first model) and compare them mutually considering other factors described above.

We assign a coefficient to declared variables *s, f, n, b* (representing the chosen criteria) by their importance. Staff and facilities have a bigger impact on the quality of a hospital than other factors so the coefficient will be 2 and budget together with environment will have assigned the coefficient 1.

Now, we can calculate the values for chosen hospitals for individual factors. We will need the number *x* representing the number of chosen hospitals from the first model.

Staff

Now we are going to describe the evaluation system we have created. We demonstrate it on the *staff*, but the same method will be used in the whole 2nd model.

At first, we need to order hospitals according to the values of s_1 **in descending order** (hospital with the highest value of s_1 will be on the first place; hospital with the second highest value of s_1 will be on the second place etc.). Then we will assign points to each hospital by its place using following formula:

$$\boldsymbol{h = x + 1 - placing}$$

h = gained number of points for a hospital

Example: If we take into account four hospitals (hospital A: s_1 = 697.68, hospital B: s_1 = 612.47, hospital C: s_1 = 598, hospital D: s_1 = 641.2) for example, number of points for each of them is:

- hospital A = 4 points (1st place)
- hospital D = 3 points (2nd place)
- hospital B = 2 points (3rd place)
- hospital C = 1 point (4th place)

Then we apply the same method for calculating with the factor s_2. To continue in the previous example, we will take the same hospitals as for the factor s_1 with values: hospital A (s_2 = 0.213), hospital B (s_2 = 0.22), hospital C (s_2 = 0.198), hospital D (s_2 = 0.22). Number of points for each of them is:

- hospital B = 4 points (1st place)
- hospital D = 4 points (1st place)
- hospital A = 2 points (3rd place)
- hospital C = 1 point (4th place)

Afterwards we count up points gained in the first ranking (s_1) with those of the second one (s_2). Then we will order the hospitals according to this sum in descending order and again we assign points to each hospital on the basis of already mentioned formula:

$$s = x + 1 - place$$

The number of points represents the intermediate value of variable *s* for each hospital. For our example it means:

- hospital A = 4+2=6 points (2nd place → $s = 3$)
- hospital B = 2+4=6 points (2nd place → $s = 3$)
- hospital C = 1+1=2 points (4th place → $s = 1$)
- hospital D = 3+4=7 points (1st place → $s = 4$)

We use these steps to make all the factors equal, so for the final value of *s* they have the same importance.

In the end, as the variable *s* has the coefficient 2, we multiply *s* of each hospital by number two, so the solution of our model example is:

- hospital D = 4*2=8 points
- hospital A = 3*2=6 points
- hospital B = 3*2=6 points
- hospital C = 1*2=2 points

Facilities

For calculating number of points for each chosen hospital we apply the same method as for the staff, because the variable *f* is divided in f_1, f_2, f_3.

We will order hospitals according to the factors **f_1 and f_3 in descending order** as we are trying to find the hospital with the larges variety of machines and with the biggest number of these.
After that, we do the same for the factor **f_2 in ascending order**, because we want the age of the machines to be the lowest possible as we want to find out which hospital is "the most modern".

Concluding it we obtain the variable *f* - we count up the points gained, we order them (in descending order), we assign them the final number of points according to the place and then we multiply it by the coefficient 2.

Environment

Also for this category of factors (we mean indoor, outdoor environment and the parking places), we use the same method as in the previous two cases.

We simply order hospitals according to the factors *i*, then *o* and finally according to *p* **in descending order**. Thanks to these three factors, we will obtain the variable *n* with coefficient 1, so we do not need to multiply.

Budget

This category is constituted by a single factor *b*, so everything we need to do is order the hospitals according to the value of this variable **in descending order** and then we assign points to each hospital on the basis of above mentioned formula.

What we obtained are 4 independent rankings of hospitals based on different criteria. To conclude them, we **count up all points gained** in each ranking. Afterwards we again order the hospitals in descending order and that will be the final ranking. The hospital which ended up on **1st place is the best one**.

References as a verification

Thanks to this precise and highly objective model of evaluation of hospitals we obtained a solution of our problem. To confirm it, we can just compare obtained result with **references** of individual hospitals written by the patients. We will not include them into our model, because they are **subjective**. But on the other hand it may be a better measure of holistic approach of the staff. We can use them **to ensure** us and then once more consider our choice.

In addition, there are still some factors, the future patient might bear in mind: whether a **helicopter** is disposal, how many **ambulances** are disposal, in case of coastal countries also **rescue boats** (rescue vehicles usually belongs to a private company), which also form part of special facilities of the hospital. We can consider also the distance from the nearest pharmacy, groceries as well as the public transport. There will be always something to add.