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AN EMERGENCY DEPARTMENT SIMULATION MODEL USED TO EVALUATE ALTERNATIVE NURSE STAFFING AND PATIENT POPULATION SCENARIOS

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ABSTRACT

Simulation models of Bethesda Hospital's three Emergency Departments were developed, based on existing processes and empirical data. Model output includes patient statistics such as wait time and treatment time, staff, and facility utilizations. Graphic animations of the models provide visual, dynamic displays of system activity. Hospital management uses the models to evaluate process performance, and preview the effects of nurse staffing and patient flow changes on the system before actual implementation of any changes.

1 INTRODUCTION

Bethesda Hospitals, Inc. is a comprehensive system of hospitals, occupational medicine centers, and related health care businesses serving the Cincinnati, Ohio area. It is comprised of Bethesda North Hospital (314 beds) and Bethesda Oak Hospital (357 beds). Bethesda Warren County is a facility providing 24 hour emergency care, diagnostic testing, physical rehabilitation services, outpatient services, and specialist physicians. Hospice of Cincinnati, Scarlet Oaks Retirement Community, Montgomery Skilled Care Nursing Home, and American Nursing Care home care nursing service are also owned and operated by Bethesda. Corporate Health Services includes CONCERN employee assistance program, SHARE on-site occupational health staff, and occupational medicine and rehabilitation centers serving business and industry.

The need for a nursing workload study was identified for the three Emergency Departments of Bethesda. A study of the existing patient classification system was conducted, and complemented by a workflow simulation, by Bethesda's Management Engineering department. Discrete simulation software was a new addition to the Management Engineering department, and modeling of the Emergency Departments was the first simulation project undertaken. The objective was to develop models of Emergency Department (ED) patient flow and staff workload that could be used on an ongoing basis to make decisions about ED staffing, scheduling, treatment area designation, and general patient flow. "What if" analysis on patient volumes, type mix, treatment area resources, and staff resources could be performed with the models to evaluate proposed changes before actual implementation. This paper describes the system model used to represent the ED, model validation techniques used, output of the model and animation of the model. In addition, uses of the model for experimentation with nurse staff scheduling and patient population re-routing are described.

The simulation model focuses on nursing workload because this project was initially part of a nursing workload-based ED patient classification system review. Other staff - registrars, clerk/ coordinators, and orderlies - are not such an integral part of ED treatment activity. Those staff resources are included in the model only insofar as they interact directly with a patient, as was observed while collecting the nursing workload data.

2 EMERGENCY DEPARTMENT PROCESS FLOW

Bethesda's three EDs have similar process flows, with a few exceptions. For instance, one of them has a Minor ED (a Fast Lane) for less acute patients, and each has a different number of treatment beds and facility layout. A common six class patient classification system is used by the three departments, but some differences are evident in its use across the three sites. Because of these discrepancies, a general process flow was first determined, and then modified to create three distinct models.

The general process contains activities which particular patients may or may not flow through. A patient's class (acuity) and type of diagnosis determine services required. A patient enters the ED by one of two modes: walkin or squad. A walkin patient is classified as one who arrives by car, bus, taxi, or on foot, and normally alone or with family or friends. A squad patient is brought by an emergency service vehicle or a private ambulance. A squad patient is immediately taken to an available treatment area; a walkin patient must first be registered and triaged, and wait for an available treatment area (unless acuity warrants immediate treatment). Once a patient is in the treatment area, a nurse performs an initial assessment, a physician sees the patient, and appropriate lab and/or X-ray procedures are ordered. The only time a patient leaves the ED treatment area is for an X-ray in Radiology when an orderly may transport the patient. All treatment by a nurse or physician is administered in the ED treatment area. Upon completion of treatment, the patient is discharged home or admitted to the hospital. The discharge activity ends the patient's ED visit.

3 SIMULATION MODEL INPUT

Required input data for the model can be grouped into two general categories: patient volume/mix data, and ED staff/activity data.

3.1 Patient Volume/mix Data

A complete representative patient arrival pattern was identified: total number of weekly ED visits, distribution of a week's patients by patient class (1 - 6), distribution of a week's visits by day of week, and distribution of daily visits by hour of day. The hourly patient arrival pattern for one ED is shown in Figure 1.

Patient mix data provides a description of the patient population: mode of entry distribution (walkin or squad), case type distribution (OB/Gyn, Cardiac, Trauma, Hand, Pediatrics, Common), patient class candidacy based on case type, and distribution of, discharge admit and discharge home. The sources for patient volume/mix data were ED logs and reports already in place in the organization, and Management Engineering (M.E.) patient classification project observation data.

3.2 ED Staff/activity Data

A representative staff schedule by day of week and half hour of day was obtained for all positions directly involved in the treatment of ED patients: registration clerks, triage nurses, ED nurses, ED physicians, ED clerks, and ED orderlies. The different positions' activity responsibilities and activity durations also were identified. The sources of this data were interviews with the ED managers and M.E. patient classification project data.

Any of the particular differences among the three EDs were also identified and prioritized for inclusion or exclusion in the models. This information was obtained from ED manager interviews and M.E. observation data.

4 THE SIMULATION MODEL

In the model, the perspective taken to describe the process is that of a patient in the ED. Model transactions represent patients flowing through the ED

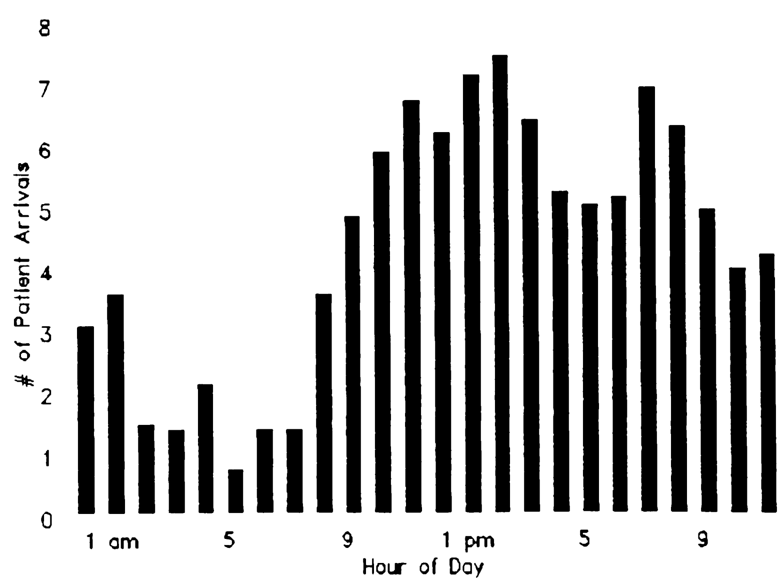

Figure 1: Hourly Patient Arrival Pattern

system. Patients arrive according to an inter-arrival distribution based on the pattern identified for the day and particular hour. Parameters are assigned upon arrival for mode of entry, case type, and patient class. Case type determines the specific treatment area selection order for assignment. Specific patient care activities (such as administering medications, hanging IVs, applying dressings, assisting with hygiene) derived from the M.E. patient observation data are grouped into appropriate categories resulting in the following process flow and staff responsibility in the model:

1. Patient Registration - by ED registration clerk
2. Triage Evaluation - by a triage nurse
3. Initial Assessment - by ED nurse
4. Seen by physician - 1st time
5. Nursing Care 1 - by ED nurse
6. Lab procedures - by a lab tech in the ED
7. X-ray procedures - by an X-ray tech in Radiology or the ED (portable unit used for acute patients)
8. Nursing Care 2 - by ED nurse
9. Seen by physician - 2nd time
10. Discharge activity - by ED nurse

Mode of entry, case type, and patient class determine the probability distributions applied in routing a particular patient through or around a particular activity in the model. Specific activity durations are dependent on patient class, and represented by a triangular distribution, which allows for the input of minimum, modal, and maximum values, obtained from M.E. detailed observation data.

Priority of treatment is based on class and mode of entry - squad patients are treated ahead of walkin patients of the same class. In the case of two or more patients attempting to capture one resource, or two patients requiring activity at the same time, the patient with the higher priority is served first. Priority level in the model is a relative value, equal to the patient's class (1-6). At only one time in the model, in the case of squad patients, is a patient's priority level changed temporarily. There it is in order to accommodate timely registration of the patient in the treatment area by a registrar.

In the case of X-ray procedures and discharge admissions (waiting for an available unit bed), an average waiting time (based on project data) is built into the activity time since no detailed data is available about Radiology's scheduling or hospital bed availability throughout the day. Because no data is available for the determination of waits for a lab tech to come to the ED, in the model, the lab tech arrives immediately when needed. It is expected that, in the future, data will be obtained to better represent the lab, X-ray and admission delays in the ED.

In modeling the system, exception cases (such as deaths in the ED) are omitted, and the following additional assumptions are applied to all three models:

1. Each patient retains a single classification throughout his/her stay in the ED. In the EDs, this class is assigned by the ED nurse and written on the patient's chart, upon discharge.
2. Patient care activities in the model are performed in single chunks of time: registration, triage, initial RN assessment, MD 1st seen, nursing care 1, lab, X-ray, nursing care 2, MD 2nd seen, and discharge. Associated direct and indirect care time are included in each activity duration. For each patient class, the distribution of total nursing time matches the sum of the individual procedures and activities observed in the M.E. project data.
3. Registration and triage activities take place for every walkin patient, regardless of patient class. Squad patients bypass these activities and are registered once in the treatment area.
4. The triage nurse does not ever take a patient directly back to the treatment area. Every patient waits for an ED nurse to bring him/her back. From the data, candidacy for such priority treatment does not appear to be solely based on patient class. For the purposes of the model, the processing of patients according to the class priority assignment was judged adequate to represent the process.
5. Staff resources are allocated every half hour, and reflect actual staffing levels. In the event that a staff person is busy with an activity at the end of his/her shift, that person finishes the activity before going off-duty, as would actually occur in the ED.
6. All treatment area and staff resources in the model (except triage nurses which are on-duty certain hours of the day) are available 100% of the time. No break time is built into the model. In the real system, ED staff breaks are not "scheduled"; they occur whenever the staff gets free, and senses there is time to take a break.
7. It is not mandated that a single nurse or physician treat a patient during the patient's stay; as any one is freed, s/he tends to a waiting patient. No treatment "zones" are designated, which are assigned in the real ED but not strictly adhered to in peak activity times.
8. Staff and facility resources are used singly by patients - only one nurse performs each designated activity, only one physician performs the diagnosis or procedure, and only one treatment area (stretcher bay) is ever used per patient. To accommodate the few cases observed in which more than one nurse tended to a patient at one time (usually in the case of an acute patient or a child), the total nursing time spent by all nurses involved is reflected in the activity durations input to the model.

9. No patients are ever transferred between beds within the ED during their stay. Patients remain in one treatment area from bring back to discharge, even in the case of holding before admission to a unit. Transfers may occur in the actual system.
10. All patients remain in the treatment area during their entire length of stay, except when undergoing an X-ray procedure in Radiology, which does occur in reality.
11. "Non-specific" (unrelated to a particular patient) indirect staff activities, such as re-stocking supply cabinets and filing paperwork, are not included in the model. These activities were not captured in M.E. patient observation data, and are activities that do not normally occur at a fixed time of the day or week, but rather whenever staff is free to tend to them. It was recommended that ED managers obtain a general estimate of the associated time by which to adjust the model output utilization statistics.
12. Reneging patients (a subset of class 1 and 2 patients, no greater than 3% of the entire patient population) who choose not to wait after they are registered and triaged, are terminated in the model immediately upon completion of triage, even though, in actuality some of them do wait a portion of time after triage. In the model, no activity is performed by the ED nurse for these cases, whereas, in reality, a chart does get printed and taken to the ED nurses' "ready to be called back" box.

5 MODEL SPECIFICATIONS

The model simulates seven days of ED activity, Sunday 12:01 am through Saturday 12:00 midnight. A warmup period of 24 hours is included, in order to begin the simulation in a realistic, mid-activity state. The majority of the input parameters is contained in external files read by the model and easily altered for experimentation without affecting the model flow.

The Personal version of GPSS/H (Wolverine Software Corporation), run on an IBM PC AT, is used for the simulation of the Emergency Department models.

PROOF (Wolverine Software Corporation) simulation animation software is used for the graphic animation portion of the project.

6 MODEL VALIDATION

In developing project plans and objectives for this project, articles explaining the use of simulation in health services were identified, three of which described Emergency Department models. One application focuses on the scheduling of staff nurses in an ED (Kumar and Kapur, 1989). Another article describes a model intended to optimize staffing and facility assignment (Ladany and Turban, 1978). A third paper compares the use of queuing and discrete simulation analysis techniques for an ED study, concluding that a simulation study has, in most cases, more potential than a traditional quantitative analysis of a system (Ortiz and Etter, 1989). *Simulation Modeling and Analysis* (Law and Kelton, 1991) provided extensive information in designing Bethesda's first simulation study. Additional resources were identified in the form of personal contact with other health care professionals and consultants involved in the application of simulation.

Several steps were taken throughout the project to validate the model and build credibility of the model and the modeler to ED and hospital management. These included an initial introduction of the ED managers to the concept and objectives of simulation as an analysis tool before beginning model development. In identifying elements to include in the model, and determining the appropriate level of detail, the management engineers who collected the ED patient observation/time study data held a brain-storming session. Through the data collection process, first-hand knowledge of each of the EDs was gained across all shifts, including usual and exception patient cases. Those issues necessary to include in the model were prioritized and respectively addressed during development of the model.

The completed models were run on a pilot basis to perform first-pass validation against actual data. The system performance measures monitored were three key time intervals of interest to management in decision-making: patient wait time, patient treatment time, and total time in the ED system. Relative frequency distributions of these times for the model's one week of activity were compared against actual results from the patient classification observation data. There was not believed to be adequate observation data to perform any rigorous statistical tests of significance; for each site there was only a sample of approximately 70 patients observed. However, the simple distribution comparison was believed to have been a relevant validation technique for this study.

After initial validation using the above method, individual meetings were held between each of the three ED managers and the modeler. At these meetings, the modeler presented the model flow, the model assumptions common to all three models, the details and assumptions particular to each facility, the validation results thus far, and the output of the then-current model. Suggestions and corrections to the model details, output, and assumptions were solicited from the manager.

Final model changes were made, the models were run with ten replications, and the results were again validated against actual data. In general, site models displayed discrepancies less than 15% between model and actual data. These discrepancies were partially attributed to natural human delay in real life, and the omission of exception cases. Given the detail and complexity of the ED models, and knowing the anticipated use of the model output, the models were deemed valid. Expected use of the models included varying input parameters and evaluating the effects of a change reflected by the change in output measures relative to the base model results. Therefore, the absolute values contained in the output become less critical than the relative differences among the tested scenarios' output values.

The ED simulation models allow the transformation of data collected on a patient basis into whole system statistics, and staff and facility utilizations. They can be used to experiment with input parameters of the process to determine effects on the system performance measures before the changes actually occur. The models can also be used in forecasting the effects of uncontrollable variables on the entire system, such as patient volume, patient class or type mix changes, and seasonal arrival patterns.

7 MODEL OUTPUT

The models produce several different output statistics at appropriate time intervals for meaningful data analysis.

7.1 System Activity Description

Output each eight-hour shift and accumulated for each day -

1. Number of patient arrivals.
2. Number of patients discharged home.
3. Number of patients admitted upon discharge.

Output for each hour of each day -

4. Average number of patients in the ED system.
5. Average number of patients waiting to be taken to a treatment area.

In addition, individual patient characteristics are recorded - mode of entry, case type, patient class - and used to analyze the population.

7.2 ED System Performance Measures

Output each eight-hour shift and accumulated for each day -

1. Average time spent in the ED system - measured from registration completion to discharge.
2. Average wait time for walkin patients before taken back to treatment area.
3. Average treatment time - measured from bring back to treatment area to discharge.

In addition, individual patient times are recorded and used to produce average times and time distributions for all patients, and each particular class (1 - 6) of patients.

7.3 ED Staff and Facility Resource Utilization

Output for each hour of each day -

1. Average utilization of each individual treatment area.
2. Average utilization of treatment area as one resource.
3. Average utilization of triage nurse.
4. Average utilization of ED nursing staff as one resource.

8 PROOF ANIMATION OF THE MODEL

The ED models were accompanied by graphic animations created in PROOF. PROOF does not operate in a concurrent mode with the model, and the memory constraints of the Personal Version of GPSS/H made intricate detail and inclusion of all staff activity impossible. However, animation of patients, nurses, and physicians was accomplished against a backdrop of a facility outline drawn to scale.

The animation portion of the project was presented to ED management only after statistical output from the models was reviewed. The animation proved useful to the modeler in debugging the model, and fostered belief in the fact that an ED is truly a dynamic environment. Peak times of the day are represented by a full screen of occupied treatment areas, busy staff and a waiting room full of patients. When patients are in Radiology for X-ray procedures, the impact of holding the ED treatment bed when other patients could be brought back is evident. Likewise in a discharge admit case, a patient may end up waiting half an hour for a unit bed, occupying an ED area. The animation reflects staff utilization by an empty nurses' station, or all nurses on-duty at a bedside, as opposed to idle nurses in the station.

The ED model output, in conjunction with the animation, comprised the mechanism for introduction of all hospital senior management to the concept and application of simulation modeling. PROOF provides extensive drawing capability which makes it easy to create hospital-specific customized icon representations of patients, staff, and equipment. Eventually, with continued use of the tool, Management Engineering will have a library of icons from which to choose for future models.

At Bethesda Hospitals, Management Engineering will always emphasize the importance of the statistical output of simulation modeling. The animation will provide a presentation format for projects when appropriate.

Appropriateness will be determined by project scope, multi-department impact, and management involved. During simulation project planning, a decision about animation will be made carefully, keeping in mind the time necessary for animation once the model is complete. It is also hoped that some process flows may be visually modeled in PROOF without being supported by a detailed logic model.

Development of animation for the ED models was judged critical in gaining acceptance of the new process improvement tool of simulation modeling at Bethesda. The animation proved to be the "proof" of simulation's benefits for those who are less oriented to viewing and understanding statistical data and graphical representations of analysis results. Along with the model, the animations will be maintained by Management Engineering for continual use.

9 USE OF THE MODEL TO EVALUATE ALTERNATIVE NURSE STAFFING SCHEDULES

One of the EDs maintained a constant nursing staff schedule seven days a week, summer and winter months of the year. Upon viewing the model output portraying the current system, that site expressed desire to improve its schedule. The focus on nursing workload during model development produced a model well-suited to experimentation with the nurse staff schedule. Improvements were sought in overall system performance measures.

Detailed simulation model output was used by ED management and staff to propose two alternative nurse schedules which better match the patient volume patterns. Another objective was to shift staff coverage from the winter months to the higher volume summer months without any effect on the entire year's budget. Alternative (A) decreased coverage between 12 midnight and 3 am seven days a week, and increased coverage between 1 and 5 pm Monday through Thursday. Alternative (B) decreased coverage between 1 and 4 am, increased coverage between 5 and 7 pm seven days a week, and increased coverage 1 to 5 pm Monday through Thursday. These changes set the staff coverage more in line with patient arrival patterns throughout the week and each day.

Table 1 summarizes the effects on system performance measures for the two schedule alternatives. All output statistics are averages calculated during the course of one day (24 hours). Either alternative schedule results in improvement in the system; alternative (B) displays slightly greater improvement than (A).

The effects on average nurse utilization were studied hourly throughout the day, and were not significant, except for slightly decreasing the range of average hourly utilization. Better alignment of staff coverage with the patient arrival pattern provides more predictable workload and improved ability to avoid over- and under-utilization.

The decision was made to modify the nurse schedule generally like alternative (B), with some coverage scheduled on-call (staff to be called in to work as needed). Since the change was recently implemented, there is no actual data against which to compare the predicted effects. In making the decision, the ED manager expressed appreciation for the value of the model output in comparing the alternative schedules. Without the models, manual calculations would have produced rough estimates, or more likely, the first alternative proposed would have been implemented, and evaluated after the fact.

Table 1: Summary of Results from Schedule Alternatives

Staff Schedule:	Current	Alt (A)	% change	Alt (B)	% change
Average # of patients in system	6.85	5.53	-19%	5.30	-23%
Average time in system [min]	127.39	102.55	-20%	98.77	-23%
Average # of patients waiting	1.85	0.90	-51%	0.80	-57%
Average wait time [min]	38.92	19.03	-51%	16.84	-57%

Base for % change calculation is the current staff schedule

10 USE OF THE MODEL TO EVALUATE ALTERNATIVE PATIENT POPULATIONS

The same ED site that proposed alternative nurse staff schedules desired to assess the impact of re-routing a certain population of patients away from the main ED to a type of Fast Lane, clinic environment. This would only be pursued if, among other things, resources for the new system could be obtained from the existing ED system, and the existing system would not be detrimentally affected. Such scenarios could be tested with the existing model simply by altering input parameters.

Initial analysis was conducted to identify the magnitude and description of the primary care population in question. Once the arrival pattern, patient class and type distributions were quantified, model input and parameter assignment logic were altered. At the time of this experimentation, the alternative (A) staff schedule had been proposed, so it was tested with the new population along with the current schedule. The time period 11 am to 9 pm was identified as the ten-hour period that encompasses the largest percentage of the primary care population, which reflects an arrival pattern very similar to the arrival pattern of all patients.

Four scenarios were run with the model:

1. Removing the primary care population 24 hours a day, and staffing by the current schedule.
2. Removing the primary care population between 11 am and 9 pm, and staffing by the current schedule.
3. Removing the primary care population between 11 am and 9 pm, and staffing by the current schedule less one nurse between 11 am and 9 pm (freeing that nurse to serve the new primary care ED).
4. Removing the primary care population between 11 am and 9 pm, and staffing by the alternative (A) schedule less one nurse between 11 am and 9 pm.

Table 2 summarizes the effects on system performance measures for the four scenarios. Re-routing the primary care patients 24 hours a day produces the maximum benefit to the existing Main ED, but is infeasible for implementation. Re-routing the patients between 11 am and 9 pm produces improvements almost as great, and would be feasible for implementation. When the patients were removed during that time period, and a nurse was also removed from the current schedule, the system performs worse than the existing system, as expected, since the current schedule does not adequately accommodate the fluctuating patient arrival pattern. Deducting a nurse from the alternative (A) schedule results in performance virtually unchanged from the existing system.

At the time of writing, no action had been taken to establish an alternative treatment environment for primary care patients. Many issues surround the perception that the primary care population hinders efficient, cost-effective operation of a hospital's ED. Output from simulation modeling is just one input to the decision-making.

Table 2: Summary of Results from Patient Population Alternatives

Population	Current	Alt 24 hrs	% change	Alt 11a-9p	% change
Staff Schedule	Current	Current		Current	
Average # of patients in system	6.85	3.66	-47%	4.23	-38%
Average time in system [min]	127.39	84.28	-34%	88.77	-30%
Average # of patients waiting	1.85	0.44	-76%	0.60	-68%
Average wait time [min]	38.92	11.93	-69%	14.49	-63%

Base for % change calculation is the current staff schedule and the current patient population

Table 2 cont'd: Summary of Results from Patient Population Alternatives

Population	Current	Alt 11a-9p	% change	Alt 11a-9p	% change
Staff Schedule	Current	Current - 1 RN 11a-9p		Alt (A) - 1 RN 11a-9p	
Average # of patients in system	6.85	7.52	+10%	6.14	-10%
Average time in system [min]	127.39	156.41	+23%	128.78	+ 1%
Average # of patients waiting	1.85	2.73	+48%	1.80	- 3%
Average wait time [min]	38.92	65.54	+68%	43.39	+11%

Base for % change calculation is the current staff schedule and the current patient population

11 CONCLUSIONS

Three simulation models of Bethesda Hospital's Emergency Departments were developed, validated, and implemented to aid in decision-making about staffing coverage and process changes. Staffing schedule changes were proposed and evaluated with the model, and when implemented, actual results will be compared to those predicted by the simulation model. The effect of re-routing the ED's primary care patient population was also studied through use of the models.

The simulation models, output, and animations were presented to ED staff, managers, and all levels of hospital management. The benefit of simulation in producing entire system performance measures from the input of individual process parameters is now understood. The capability to test process changes before implementation is believed critical in managing the many process improvement and cost reduction opportunities presently being pursued by Bethesda Hospital. Although the ED models are not an example of the use of simulation to design an entirely new facility and process, that potential was recognized through understanding the ED project, and the concepts and methodology surrounding simulation modeling. Other hospital departments and processes have been selected for study using simulation, now that the Emergency Department models were successful applications of simulation modeling in a hospital environment.

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